NASA CR-112325

EARTH ORBITAL EXPERIMENT PROGRAM
AND
REQUIREMENTS STUDY

VOLUME I

SECTIONS 1 THROUGH 6

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOREWORD

The information presented in this report summarizes three major steps toward production of a reference manual for planners of manned earth-orbital research activity. The reference manual will serve as one of the principal tools of a systems approach to experiment and mission planning based on an integrated consideration of candidate research programs and their attendant vehicle, mission, and technology development requirements.

The first major step toward preparation of the manual was the development of long-range goals and objectives suitable for NASA's activities during the 1970-1980 time period. This work was completed by NASA Headquarters with active center support and was published in September 1969 as a portion of a report for the President's Space Task Group entitled, "America's Next Decade in Space."

The second major step was a contractual study effort undertaken in September 1969 by McDonnell Douglas Astronautics Company-West with the TRW Systems Group, the IBM Federal Systems Division, and the RPC Corporation. The purpose of the study was to structure the NASA-developed goals and objectives into an orderly, system-oriented set of implementation requirements. The contractor examined, in depth, the orbital experiment program required to achieve the scientific, technological, and application objectives, and determined in a general way the capabilities required in future manned orbital programs to accommodate the defined experiments. Thus, the basic task of the contractor was to aid NASA in studying the useful and proper roles of manned and automated spacecraft by examining the implementation alternatives for NASA experiments.

The third major step presented in this document is the result of an integrated consideration of NASA's long-range goals and objectives, the system and mission requirements, and the alternative implementation plans. It will serve as a source of detailed information and methodology for use by NASA planners in development and justification of future programs.

Management

Technical direction (fig. 1) of the contracted study effort is the responsibility of the Advanced Aerospace Studies Branch (AASB) of the Space Systems Division (SSD) at the Langley Research Center (LRC). Technical guidance is provided by the Earth Orbital Experiment Program Steering Group which reports through the Planning Steering Group (PSG) to the Associate Administrator. Technical coordination is also maintained with appropriate personnel at ARC, GSFC, MSC, and MSFC.

The membership of the Steering Group (fig. 2) comprises representatives of the working groups of the PSG under the chairmanship of Dr. R. G. Wilson, Director, Advanced Programs, OSSA. The NASA Study Management Team is headed by Mr. W. R. Hook of the AASB. Technical support is supplied by elements of the Langley Research Center as required.

The contractor's Study Team is headed by Dr. H. L. Wolbers, MDAC, and the Senior Management Review Council is chaired by Mr. C. J. Dorrenbacher, Vice President, Advanced Systems and Technology, MDAC.

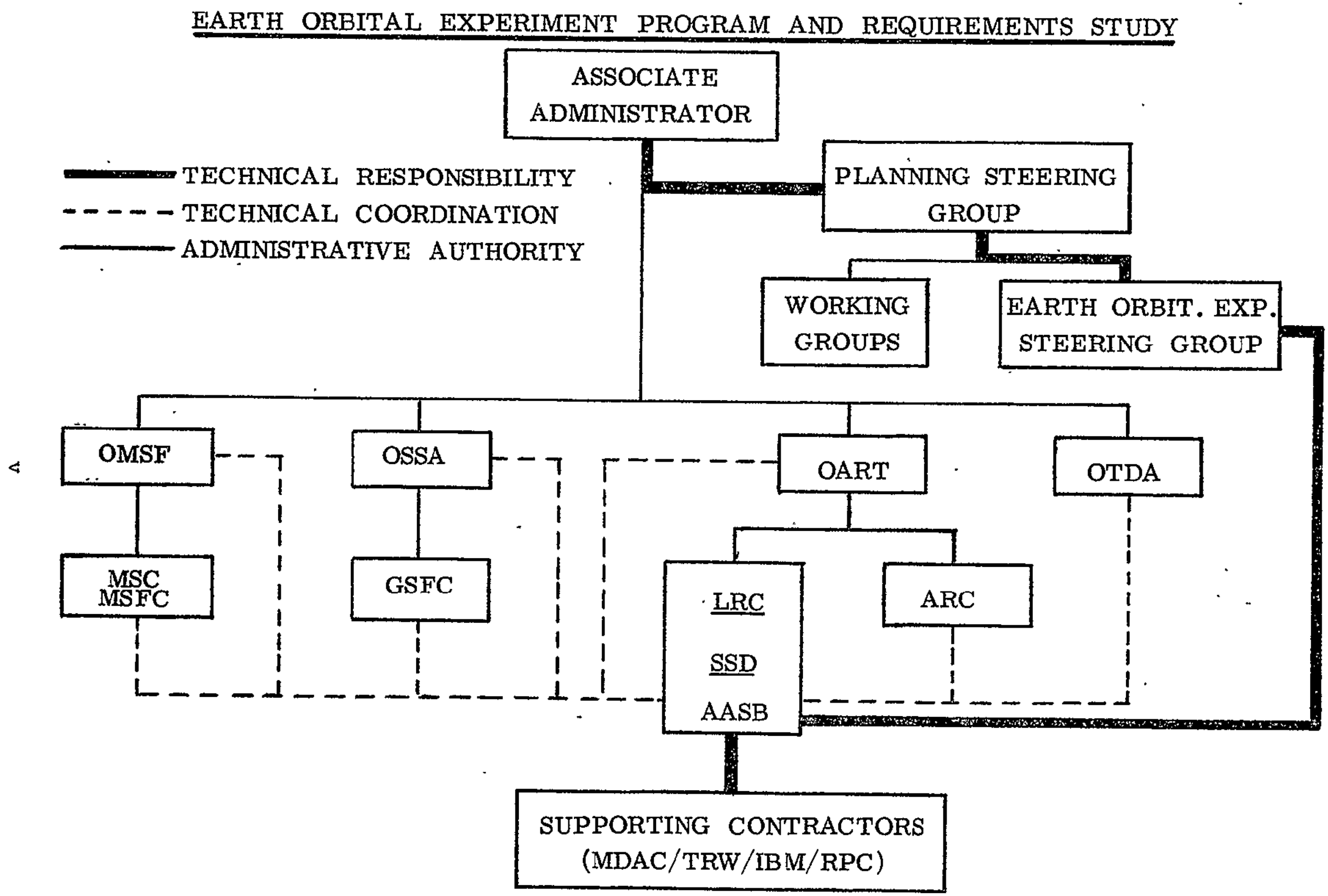

Figure 1. - Management Plan.

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

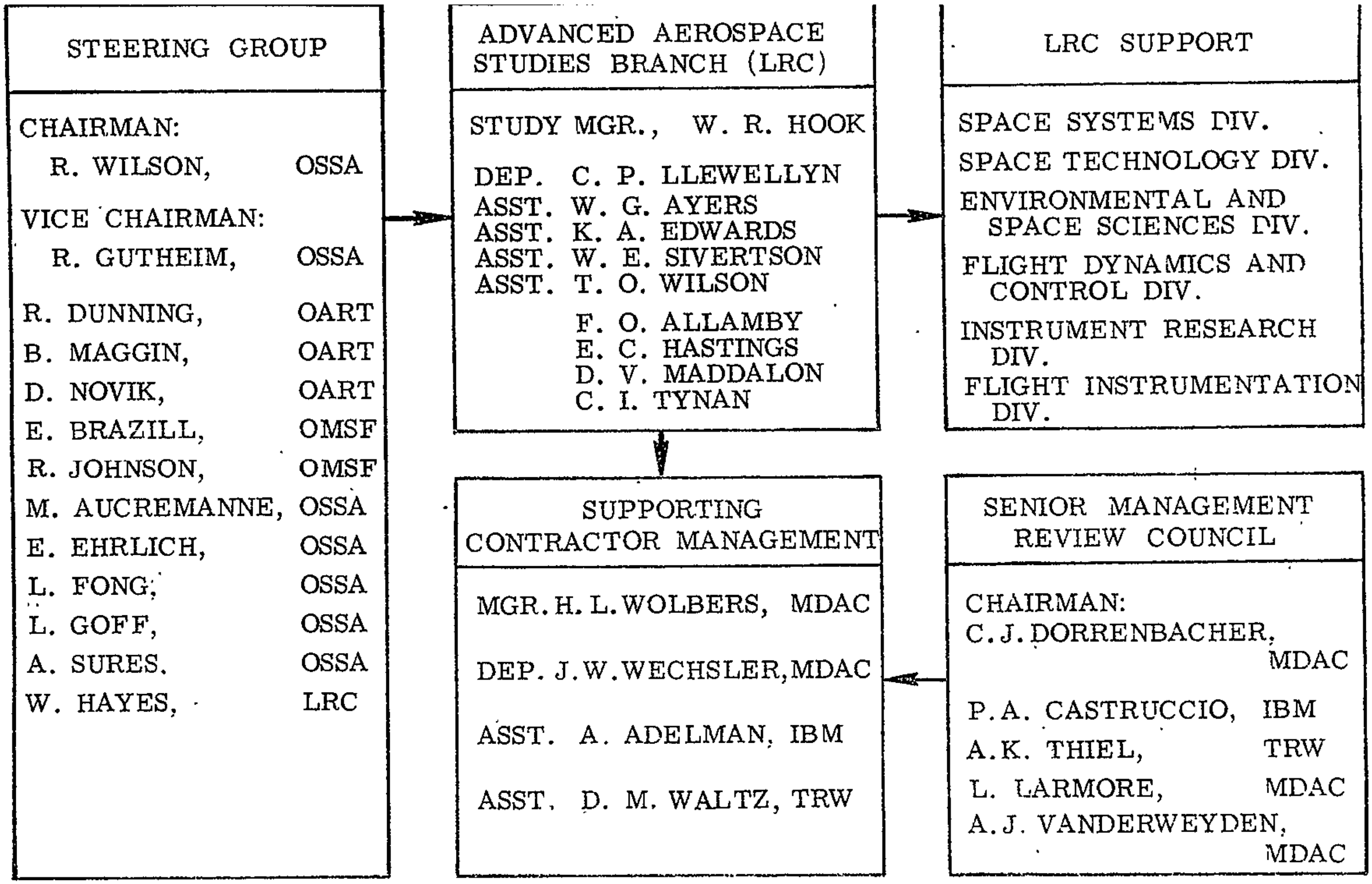

Figure 2. - Study Team

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SECTION I

INTRODUCTION

NASA's decision makers are continually faced with a broad spectrum of alternative courses of action from which they must select those long-range program options that appear to offer the greatest potential benefits for a given allocation of resources. Long-range planning is desirable because it offers assurance that required systems and equipment can be available by the time they are scheduled for use while it also recognizes that unexpected events contribute to scientific insight and thus influence subsequent implementation. Stated differently, while rigid on-board requirements may expedite the design of space facilities, they must not be allowed to preclude the capability for innovative research. In recognition of these factors, the work reported in this document was predicated on providing concepts of research activities structured well enough for initial planning and for derivation of facility requirements, but flexible enough to permit change as additional needs and objectives become defined.

The Earth Orbital Experiment Program and Requirements Study was initiated to assist NASA in the analysis and organization of its research objectives for earth-orbital platforms and in identifying the attendant programmatic implications of their integration and implementation. The principal results of the study have included:

Candidate orbital research activities
Requirements placed on orbital research facilities
Supporting technological developments needed.

Emphasis has been placed upon research activities in which manned participation can be expected to make a positive contribution, but the analysis was conducted so as to avoid commitment to existing concepts or hardware. This approach fostered the generation of a reference framework of potential research activities that is flexible enough to be used by program planners in investigating implementation options. While the analysis presents a static picture representative of the time during which it was compiled, the philosophy of the analytic approach is not time-dependent, and the planning framework and information structured upon it must be updated periodically to maintain a current model that can be used effectively by managers and decision makers. It should also be noted that while the plans which were generated during the study are important, the planning process is perhaps even more important since the "people relationships" which are established during any formal planning activity provide the "working fluid" needed for maximizing opportunities in a changing national environment.

The ultimate objective of this study then is to reduce uncertainty in the planning of space research activities and in the design of the associated space facilities. Research is a dynamic phenomenon and future facilities must fulfill the needs of the scientific community to as large an extent as possible, with flexibility for change as new data stimulate formulation of new objectives.

The scope of the program developed in this study includes scientific and technological research which would benefit from a space capability. Six scientific and technical disciplines were analyzed: Manned Space Flight Capability including the subdisciplines of Biomedicine, Behavioral Research, Man-Machine Integration, Life Support and Protective Systems, Engineering Development, and Operations Development; Space Biology; Space Astronomy; Space Physics; Communications and Navigation; and Earth Observations, including the subdisciplines of Earth Physics, Agriculture and Forestry, Geography and Cartography, Geology, Hydrology and Water Resources, Oceanography and Marine Resources, and Meteorology. Research for which space platforms were found to be of value was considered for both manned and automated operations. The availability of man was assumed, and the assignment of an activity to the manned or automated category was predicated only on whether man's participation might enhance of detract from the achievement of the research objectives. Criteria used in this determination involved consideration of man's usefulness as an in-orbit scientist-observer (for sensor selection, data analysis, etc.), development engineer (for target selection, parameter variation, etc.) and technician (for equipment setup, maintenance, etc.). Risk to the crew (extreme environment, physiological limits, physiological stress, and physical hazards such as sharp protuberances, high voltages, explosive materials, and noxious, toxic, or otherwise reactive materials) and ways in which man would degrade or disturb the experimental measurements were also considered. Typical of the latter are acceleration disturbances associated with manned vehicles (Space Biology, for example, requires disturbance-free environments of 10^{-4}g or less for extended periods) and effluents released (environmental contamination) from manned systems. Relationships of candidate research activities to ongoing programs were also established. Meaningful areas of research not being addressed by current programs were used for defining the program planning factors vital to identification of future space program alternatives.

The broad program objectives were the result of a NASA-wide planning effort which established the basic guidelines for the study. As the study progressed, the NASA study team adjusted the relative emphasis on objectives in respo se to prevailing interest and state of readiness.

The initial stage of the study was devoted to development of a comprehensive overview of research objectives for each of the six disciplines. The basic approach is described in Section 2, Critical Issues for Research, and was essentially the same for each discipline. The research problems of significance were identified by repeatedly subdividing the NASA-defined objectives in a logical manner. This process was augmented by consulting the literature and was validated through personal discussions with recognized authorities in each discipline. Ultimately, the subdivision of objectives led to the identification of what were termed "critical issues" in each discipline which are defined as those important questions which are of crucial interest to competent authorities and to which answers will be decisive in meeting a central objective

After the critical issues for each discipline were identified, the information required to address each issue was established, and the measurement programs necessary to obtain the desired information were hypothesized. The characteristics of space activities that would be of importance in implementing the measurement programs were then examined, and those critical issues for which the vantage point of a space platform would be of value were identified. This identification of potential candidates for space research is described in Section 3, Screening and Grouping of Critical Issues, and involved consideration of orbital characteristics, areal and temporal coverage, and environmental characteristics such as zero gravity, vacuum, radiation and atmospheric attenuation. Many of the critical issues were found to share common information and measurement needs, and it was determined that those critical issues could be grouped into meaningful units. Accordingly, 136 such groupings of critical issues (termed research clusters) were derived and provided the basis for more definitive research facility requirements.

Observation requirements, mission parameters, apparatus performance requirements, and facility resource demands, including data acquisition requirements and the options for data management in manned systems, were identified for each of the 136 research clusters and are described in Section 4, Research Cluster Descriptions. The measurement, facility, and operational requirements for each research cluster are documented in Appendix C. The general classes of mission and spacecraft requirements derived from analysis of the research clusters are summarized in Section 5, Research Mission Planning Requirements, and a technique is presented whereby the sensitivities of space facility requirements to grouping variations can be examined.

Thus, the experience and specific information developed by NASA were used to provide orbital research program objectives in the six disciplines with a continuous chain of traceable logic from the objectives in each discipline to the detailed descriptions of specific experimental activities necessary to consummate the research program.

As the initial step toward defining the development costs of the many alternative programs, the supporting technology development (STD) requirements for each of the research areas were identified in Section 6, Supporting Technology Development Requirements. Review of the research objectives, critical issues, information needs, and measurement requirements led to identification of areas that require further theoretical studies and/or exploratory investigations before the orbital research programs can be implemented. Analysis of experiment descriptions, as well as data, mission, and spacecraft requirements, in turn suggested requirements for new support equipment, methods, and techniques. In Section 6, the subject of technological forecasting is addressed, and the current technology gaps that were identified in each of the six disciplines are discussed.

The principal products of this study are:

- A logical derivation of 3,800 critical issues whose answers contributed to the NASA-specified objectives of the research program in the six disciplines of the study.
- A grouping of the 1,900 most pertinent critical issues into 136 research clusters that can be used as the building blocks of an earth-orbital research program. For each of the research clusters, specific information is provided on the purpose and nature of the research activity as well as on the requirements that the activity will place on a space facility.
- Identification of over 200 items of STD that must be accomplished during the preparative development cycle to support the activities of the various research clusters. These STD requirements are identified with the research clusters for which they are needed so that the importance of individual items may be properly assessed in analyzing the effects on the overall program of adding or deleting research objectives.

It was previously stated that research, by its nature, is dynamic and conclusions drawn here are inherently transient. However, three particularly significant points should be noted. First, the traceability provided in relating critical issues, information needs, measurement requirements, and STD items to the objectives of a given discipline aids the planner in assessing the impact that the elimination of specific objectives would have on the development of space facilities, and conversely, the impact that the failure to provide specific space facilities might have on the accomplishment of major goals or objectives.

A second significant result of the study is the development of new insights into the real value of a manned research facility. In Communications, for example, it was determined that the flexibility of a manned system is essential to the efficient measurement of propagation, noise, and radio frequency interference effects. In Space Biology, it was found that by utilizing man's ability to participate directly in the experiment activities, the number of answerable critical issues was increased tenfold.

A third salient result is the finding that no individual research area caused a sizing constraint on the onboard data management systems of future space systems. The sizing of the data management systems will be predicated more on the operational requirements of the specific space facility or vehicle than upon the research to be conducted. The earth resources activities, which previously had been thought to place excessive demands upon data management systems, in fact did not. In this area, especially, a wide disparity was found between peak data rates and average data rates, and the resultant impact on the data management system therefore is highly dependent upon experiment scheduling and timeline analyses.

It was further determined that the most important concern from the overall data management standpoint is what to do with data once it has been received on the ground. Current budgets are inadequate for analysis of the data already accumulated, and the development of techniques to make effective use of data gathered in future systems must be considered as an integral part of planning.

Other general findings are summarized below:

- In research activities directed toward development of an advanced manned spaceflight capability, there are few mission constraints other than operational or safety hazards. The primary requirement is for extended periods (years) of weightlessness.

- Space Biology relies heavily on conducting scientific investigations onboard or adjacent to a manned spacecraft. Low acceleration levels (10^{-4}g, or less) over extended periods may be a major operational constraint. Potential contamination from biological materials and chemical reagents will require precautions to ensure crew safetv.

- Space Astronomy imposes severe pointing and stabilization requirements on any space platform. Extended periods at synchronous altitudes are desired, particularly for optical observations, to minimize target acquisition and tracking synchronization errors for long-duration observations (8 to 12 hours). Free-flying, remotely controlled modules are therefore conceived for many astronomy missions, with periodic visitation by technicians for maintenance and checkout.

- A number of Space Physics research activities are characterized by high power requirements (peaks to 20 kw), severe thermal loads, and critical environmental control. Crew skill requirements are extremely demanding for onboard operations. Materials used in physics and chemistry investigations may pose problems to crew safety. Certain areas of material research may require disturbance-free environments with acceleration levels less than 10^{-6}g, for extended periods.

- Communications and Navigation research in space will require close coordination with ground activities. Long-term statistical information over broad ranges of the RF spectrum will require onboard analysis and maximum flexibility for equipment reconfiguration.

- Earth Observations will be paced by target viewing opportunities. Although data rates will be high during specific segments of any mission, the average data rate will continue to be low in the foreseeable future. Technology items relating to the development of remote sensors, especially those in the multispectral microwave class, will be perhaps the most critical.

- Considerable commonality was found among the STD requirements in the various scientific and technical disciplines. In the area of Earth Observations, for example, 12 percent of the STD items affected over 75 percent of the experiment groups and therefore were important to approximately 75 percent of the critical issues.

- An especially critical technology need is the development of equipment for the processing of high-resolution photographic film in zero gravity.

Section 2

CRITICAL ISSUES FOR RESEARCH

The scientific and technical breadth of the Earth Orbital Experiment Program and Requirements Study reflects the scientific and technological investigations judged by NASA to be appropriate for inclusion in its earth-orbital research programs. This breadth was established in terms of six scientific and technical disciplines, expanded in a NASA-wide compilation of objectives, and elucidated in conferences with personnel at NASA Headquarters. The disciplines are:

1. Manned Space Flight Capability
2. Space Biology
3. Space Astronomy
4. Space Physics
5. Communications and Navigation
6. Earth Observations

2.1 ORGANIZED OVERVIEW METHOD OF ANALYSIS

To derive a program of research in each of the disciplines, and from this subsequently to establish requirements for an orbital research facility, it was necessary to begin by considering the content of each discipline. It was required that a comprehensive identification of the important areas of interest in the discipline be developed through a procedure that could be followed in a straightforward manner. The procedure used in this study, is described as an organized overview analysis.

The organized overview analysis is essentially a process of describing a discipline by working in an organized fashion from an identification of the overall objective of the discipline, and repeatedly subdividing this objective into contributory subobjectives. The entire discipline is thus subdivided into "critical issues" appropriate for specific research.

A critical issue is a question, derived from the basic objectives in a discipline, for which progress in the discipline requires an answer during an impending time period of interest and whose scope is appropriate to a research endeavor.

At this level of subdivision, the subobjectives of a particular discipline can be examined for timeliness (i.e., whether progress in the discipline requires timely accomplishment) and applicability to a given mode of research (e.g., whether the research must be done in association with a manned space platform). The critical issues resulting from selecting the objectives within the disciplines that satisfy these criteria can then form the basis of a program of research utilizing manned space platforms.

The ability to identify the research needed to satisfy a specific objective is inherent in the nature of the overview analysis. Starting from the objectives of a given discipline, a framework is established that makes it possible to include all known aspects of the discipline in the consideration.

The orderliness of this methodology is a powerful influence in assuring that the elements of the subject will be recognized, since the procedure draws out the full range of the knowledge and experience of the persons performing the analysis. The organized overview also tends to generate constructive suggestions from qualified persons who are not directly involved in the analysis but with whom the analysts may confer. These suggestions may relate to groupings of items already identified or to the identification of items not previously included.

The natural ordering that is characteristic of this type of analysis helps to clarify the relationships among the various elements of any program devoted to the discipline in question. This characteristic assists in justifying proposed activities on the basis of their relevance to a broader scope of activity. (For example, see References 2-1, 2-2, 2-3, and 2-4).

Objectives derived through the organized overview procedure benefit from a logical place in the overall scheme of the discipline being analyzed. This credibility is enhanced by the fact that the overview tends to be stable over long periods of time. Changes that may be induced by progress in the discipline can generally be accommodated within the basic structure. In this way, the analysis can exhibit flexibility in adapting to new information and exhibit a basic stability for purposes of long-range planning.

Figure 2-1 portrays the organizational approach taken in the analysis. For ease of reference, each analytic level was coded with a decimal notation to designate its relationship to the objectives, subdisciplines, subobjectives, and critical issues.

The analysis of any discipline is keynoted by a brief, specific statement that summarizes the scope. Each statement, which is essentially a definition of the discipline, is an interpretation of the two- or three-word title used to identify the discipline throughout the study.

The most far-reaching step in developing the organized overview is that of dividing the discipline into major subdiscipline groupings which helps to develop and to structure the principal activities to which the ultimate research program will be devoted.

The principal analysis in developing an organized overview is the development of each subject below its major subdiscipline groupings where it is necessary to subdivide the stated objectives into contributory subobjectives and to cascade this operation several times to reach an effective degree of separation.

The essential step in subdividing the objectives at any level is to restate an objective, in the form of several contributory objectives, each in question form, in such a way that the group of resultant objectives, taken together, is the equivalent of the initial objective.

The purpose of repeatedly subdividing the objectives is to translate the discipline's basic objective into contributory elements--in an organized manner that is not likely to overlook any of the logical derivatives of the basic objective--each of which is sufficiently narrow in scope to be approachable as a manageable research activity. The subdividing process is guided to reach the research-sized questions within a reasonable number of subdividing

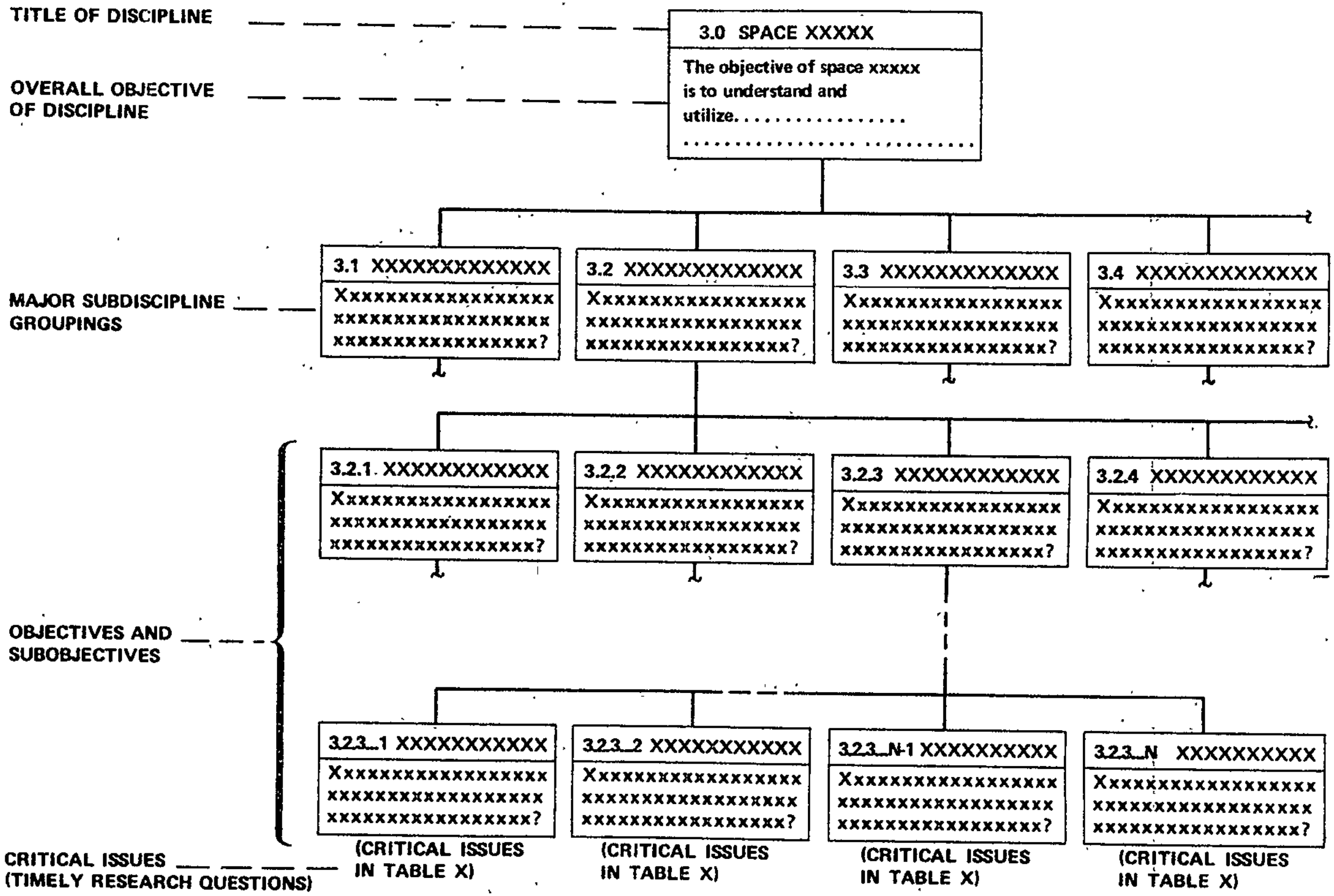

Figure 2-1.- Framework of Organized Overview Charts.

levels, typically about one-half dozen. The individual decisions by which the subdividing process is guided and the judgment as to what constitutes a research-sized question (so that the subdividing may be terminated) are both recognized as judgment factors that reflect the experience of the individual analyst and for which no set rules have yet been established.

The final step in the organized overview analysis, which is manifested at the lowest level in the chart is the specification of critical issues.

Knowledge of the techniques that have proved most valuable in implementing the organized overview analysis procedures will facilitate an understanding and appreciation of the analyses themselves, which are presented in Subsections 2.2 through 2.7. This knowledge will also serve to document the current state of capability for organized overview analysis so that future efforts alon, the same lines may benefit from the experience gained in this study.

An organized overview analysis is best addressed by a group of two to four imaginative persons who are well versed in the discipline or segments of it. The work should include both individual and group sessions. The principal purpose of the group sessions (sometimes referred to as "brainstorming") is the stimulation of ideas. The individual sessions serve the complementary purpose of organizing and evaluating some of the ideas developed in the group sessions, and provide opportunities for individual thinking and investigation of source material.

In addition to developing their own ideas as far as possible, the analysis team should also make appropriate use of external information concerning each discipline. Two principal sources are important in shaping the organized overview. The literature in the discipline provides much information on the level of knowledge already achieved and suggests areas in which the frontiers of knowledge can be expanded. Also, source documents on research and other programs relating to the discipline are important in guiding the general trend of the overview in the most relevant and productive direction.

It is best to approach the source material from the point of view of organizing and taking account of existing knowledge only. No attempt should be made to develop new knowledge as a part of the organized overview analysis. New knowledge is sought through actual research; the organized overview analysis procedure is merely a step in the planning of research.

While it is advisable for the analysis team to carry the organized overview to a substantial state of completion by itself, the work should not be considered final until it has had the benefit of examination by other persons who are qualified to perform the analysis in whole or in part. Colleagues within the same organization as the analysis team should be consulted for review and critique of the analysis. It is even more important that competent authorities whose opinions and judgment in the involved discipline are respected in the scientific community should have the opportunity to examine the organized overview and to comment on its validity, its effectiveness, areas of possible omission, and details of execution.

The importance of submitting the organized overviews to competent outside authorities cannot be overstated. Although a small, closely knit working group is best suited to the mechanics of such an analysis, the nature of the material developed and its intended use make it imperative that the results have the concurrence of a broad base of qualified persons.

A number of quantitative rules and limitations regarding the development of the organized overview charts have been found useful. First, the items presented at any subdivision juncture (i.e., the items into which any given item is subdivided) should be inclusive, yet mutually exclusive. In other words, to the extent possible, the group of items resulting from the subdivision should, as a whole, cover all of the subject matter implied by the initial item; but at the same time, no aspect of the initial subject matter should be covered by more than one of the subsidiary items.

Each subdividing process should also be definitive (i.e., it should produce enough newly stated ideas to justify the subdivision) but mentally integrable (i.e., it should not produce so many newly stated ideas as to be overly difficult for the mind to absorb). To satisfy these constraints, a rule of three to seven appears advisable. If a subdivision contains fewer than three branches, it should probably be combined with another subdivision; if it contains more than seven branches, it should probably be split into two or more separate subdivisions.

Finally, to keep the scope and effort of the analysis within practical, useful limits, it is advisable to try to limit the entire organized overview chart (from the overall objective of the discipline at the top to the critical issues at the bottom) to a total of about seven levels.

2.2 ORGANIZED OVERVIEW ANALYSIS OF MANNED SPACE FLIGHT CAPABILITY

2.2.1 Overview of Objectives

2.2.1.1 Major Subdiscipline Divisions

The broad objectives in the area of Manned Space Flight Capability are to:

1. Select, develop, and conduct scientific, technological, and applied experiments that are advantageously associated with a manned system.

2. Develop and demonstrate practical concepts for establishing, operating, and maintaining a long-duration space station(s) involving significant increases in useful life.

3. Use earth-orbital manned flights for testing and developing equipment and operational techniques applicable to lunar and planetary exploration.

4. Improve the effectiveness and lower costs of manned spaceflight systems and operations.

5. Identify, evaluate, and exploit the economic, scientific, technical, social, and geopolitical implications of a long-duration manned space facility.

6. Contribute, through both technological and hardware development, to the national security.

The scope of the Manned Space Flight Capability descipline in the present study was limited to the three areas of Space Medicine, Engineering Experiments, and

Operations Experiments. Within the area of Space Medicine, the three further subdivision of Biomedicine, Man-System Integration, and Life Support and Protective Systems were included. This was done to achieve compatibility with the disciplines discussed in a concurrent Biotechnology Laboratory Requirements Study (Reference 2-5) and with the disciplines under the cognizance of the NASA Aerospace Medicine Steering Group.

2.2.1.2 Format of Overview Structure

The format for analyzing Manned Space Flight Capability is shown in Chart 1-1 in Appendix A. Each of the major categories is discussed below.

Manned Space Flight Capability (1.0)*

The overall objective is to sustain man in long-term space missions and to qualify the systems and operations that support him. To meet this objective, it is necessary to obtain data during long-duration orbital spaceflight, to make alterations in accordance with these data, and to evaluate the results of these alterations in later flights.

Space Medicine (1.1)

The objective for Space Medicine is to achieve optimum utilization and support of man in advanced space systems. For purposes of this study, Space Medicine includes Biomedicine, Man-System Integration with its two subdivisions of Behavioral Research and Man-Machine Research, and Life Support and Protective Systems.

Biomedicine (1.1.1)

The specific objectives for Biomedicine are the following:

1. Determine the extent of, and develop methods for, assessing cardiovascular adaptation to acceleration, weightlessness, and subgravity states.

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*The decimal notation shown in parentheses in this and succeeding subsections designates the relationship of each level within the overall hierarchy of objectives, subdiscipline groupings; subobjectives, and critical issues.

2. Describe the qualitative and quantitative alterations evoked by space flight relative to hematologic, immunologic, and biochemical effects.

3. Determine spacecraft gaseous atmosphere requirements for various space missions, including safety limits for toxic inhalants.

4. Determine the effects of space flight on respiratory functions and mechanisms, to include dysbarism, maintenance and optimal crew physical conditioning, and the assessment of the metabolic cost of physical activity at null and subgravity levels.

5. Investigate and evaluate the effects of space flight on neurophysiological functions, including equilibrium, coordination, sleep, alertness, biorhythms, and visual and other special senses.

6. Determine the extent to which the musculoskeletal system adapts to space flight and subgravity states, and to provide appropriate in-flight monitoring capability, and countermeasures to assure maintenance of the physiological integrity of this system.

7. Determine the variations in and physiological significance of total body water distribution during adaptation to space flight and subgravity states. Mineral and electrolyte requirements are to be assessed in conjunction with the fluid balance studies. As a necessary concomittant, renal function is to be assessed.

8. Define nutritional requirements for space missions, improve food acceptability, and assess the effects of space flight on the gastrointestinal tract, including nutrient ingestion, digestion, absorption, management of ingested gases, and elimination. Also included in this objective is the assurance of potable spacecraft water in terms of both chemical and biological acceptability.

9. Define the effect of space flight on the endocrine system and develop the capability of utilizing the endocrine and other appropriate systems for monitoring stress and measuring degrees of stress intensity.

10. Identify and control the potential microbiological problems of man in spacecraft with closed or semiclosed ecological systems, including quantitative containment techniques.

11. Assure that human (biodynamic) tolerance limits for acceleration, vibration, and noise are defined for specific missions.

12. Determine the space radiation effects and hazards of space operations and define protective measures.

13. Develop instrumentation for the measurement of body functions and provide a data management system to meet this objective.

14. Define and develop predictive, diagnostic, and therapeutic procedures, medications, and equipment to maintain the health and well-being of the crew.

15. Determine the effects of, and requirements for, various gravity levels for extended space operations to improve crew habitability.

An analysis of these objectives showed that most of them (1, 2, 4, 5, 6, 7, 8 and 9) involve an assessment of the effects of the space environment, particularly the weightless aspect, on various physiological systems. Others (3, 11, and 12) are concerned with the effects of stresses other than weightlessness against the background of the space environment; and others (10 and 14) are related to medical problems other than adaptative physiological changes. Objective 13 deals with instrumentation, whose requirements will be defined with the progression of research and experience. Objective 15 is related to habitability and crew performance, which are analyzed in a different section of the study.

Analyses of Biomedicine information requirements in the three general categories indicated above facilitated the generation of possible experiments as well as anticipating potential problems. Three initial questions (Chart 1-2 in Appendix A), are posed.

1. What changes occur in the physiological systems of man when he is exposed to the spacecraft environment for prolonged durations, and what are the mechanisms associated with such changes?

2. What are the effects of the spacecraft environment on medical problems and their management?

3. What changes occur in tolerance limits to environmental stresses due to prolonged exposure to the spacecraft environment, and how will these changes affect environmental control criteria?

Man-System Integration (1.1.2)

The objective for Man-Systems Integration is to understand, predict, and enhance man's behavioral capabilities in space and to develop design criteria and technology for the space equipment with which man interacts. This disciplinary area was further subdivided into Behavioral Research (Item 1.1.2.1) and Man-Machine Research (Item 1.1.2.2). Subobjectives for these two areas are as follows (Chart 1-3 in Appendix A):

1. Behavioral Research-To understand man's performance and behavior, both as an individual and as a group member; to determine how he can most efficiently perform useful work in space; and to identify effective selection, training, and performance assessment techniques.

2. Man-Machine Research-To identify design criteria for equipment with which man interacts, develop habitability support to permit adequate task achievement, and define and develop scheduling techniques and appropriate performance aids.

Man-Systems Integration research includes those aspects described in the "Candidate Experiment Program for Manned Space Stations," NASA Document NHB 7150XX, 15 September 1969 ("Blue Book") within Functional Program Element 5.14 under the following headings: (1) Human Performance Capabilities and Design Criteria; (2) Selection, Training, and Proficiency Maintenance and Assessment; (3) Individual and Group Dynamics; (4) Operator Equipment and Technology; and (5) Habitability.

The arrangement of the overview analysis is consistent with (1) the work performed in the Biotechnology Laboratory Requirements Study (Reference 2-5) and (2) the NASA Long-Range Plan for Aerospace Medicine (15 June 1969). All of the research contemplated within this effort is of an experimental rather than a flight test nature. The intent was to identify specific research that must be performed to provide data on man's behavior and on man's interaction with hardware features.

Life Support and Protective Systems (1.1.3)

The Space Medicine objective for this category of work (Chart 1-4 in Appendix A) is to develop the design criteria for highly reliable life support and protective systems that are required to support and protect man and to enhance his capability to perform space operations. This area is hardware-oriented, the experimental content similar to that contained in Engineering Experiments.

Engineering Experiments (1.2)

The objective (Chart 1-5 in Appendix A) is to develop and evaluate technology and equipment for spacecraft components and subsystems with which man interacts or which are required to provide manned space flight capabilities. Engineering Experiments consist of specific, time-phased series of events in which hardware is flown in orbit and measurements are taken, not only of hardware parameters, but also of man's behavior in interacting with the hardware.

It is assumed that these experiments will be carried as secondary subsystems in addition to the prime subsystems that have already been qualified. The experimental subsystems might, however, be used periodically to support the space platform with the primary systems temporarily in a standby mode. It is anticipated, for example, that a biowaste propulsion engineering experiment could provide propellant for resistojet thrusters to augment the regular spacecraft attitude control subsystem.

<u>Operations Experiments (1.3)</u>
The primary objectives in this research area (Chart 1-6 in Appendix A) are: (1) to develop the operational capability to establish, conduct, and support manned space activities; and (2) to develop and evaluate techniques for space logistics, maintenance and repair, assembly and deployment, module operations, and vehicle support operations. It is anticipated that research in this area would be performed using operational systems, rather than strictly experimental systems as in the case of Engineering Experiments.

2.2.1.3 Rationale for Subdivision of Objectives
Major objectives for each of the principal areas of Manned Space Flight Capability were subdivided as follows:

<u>Biomedicine (1.1.1)</u>-What are the effects of a long-term space flight on human physiology and behavior?

<u>Physiological Changes (1.1.1.1)</u>-The analysis of the first biomedical objective considers physiological changes produced in response to the weightless environment, and follows the classical breakdown of the body into physiological systems, with changes in bone, muscle, temperature control, and exercise being related to the general area of metabolism. The divisions selected and basic questions to be answered are:

<u>Cardiovascular Changes (1.1.1.1.1)</u>-What changes occur in cardiovascular function, and what are the mechanisms associated with the changes? (See Chart 1-7 in Appendix A.)

Respiratory Changes (1.1.1.1.2)-What changes occur in respiratory function, and what are the mechanisms associated with the changes? (See Chart 1-8 in Appendix A.)

Neurological Changes (1.1.1.1.3)-What changes occur in neurological function, and what are the mechanisms associated with the changes? (See Chart 1-9 in Appendix A).

Gastrointestinal Function (1.1.1.1.4)-What changes occur in gastrointestinal function, and what are the mechanisms associated with the changes? (See Chart 1-10 in Appendix A.)

Excretory Function and Fluid Balance (1.1.1.1.5)-What changes occur in excretory function and fluid balance, and what are the mechanisms associated with the changes? (See Chart 1-11 in Appendix A.)

Metabolic and Musculoskeletal Function (1.1.1.1.6)-What changes occur in metabolism, including musculoskeletal function, and what are the mechanisms associated with the changes? (See Chart 1-12 in Appendix A).

Hematology and Immunology (1.1.1.1.7)-What changes occur in hematology and immunology, and what are the mechanisms associated with the changes? (See Chart 1-13 in Appendix A.)

Endocrine Function (1.1.1.1.8)-What changes occur in endocrine function, and what are the mechanisms associated with the changes? (See Chart 1-14 in Appendix A.)

Reproductive Changes (1.1.1.1.9)-What changes occur in reproductive function, and what are the mechanisms associated with the changes?

Medical Problems (1.1.1.2)-The analysis of medical problems (Chart 1-15 in Appendix A) considers the various types of ground-based problems that would be likely to arise in the spacecraft. The various types of infectious diseases are not considered individually, but the general problem of microbial contamination and infection is examined, in addition to changes in response to drugs and medications. Diagnostic and predictive signs and preventive measures are also examined in relation to both medical problems and physiological changes. The analysis of medical problems and their management produced the following subobjectives:

Response to Medication (1.1.1.2.1)-What changes occur in the response to medications, and how will the changes influence dosage levels?

Microbial Infections (1.1.1.2.2)-What changes occur in microbial infections, and how will these changes influence sanitary procedures?

Traumatic Injuries (1.1.1.2.3)-What changes occur in the healing process following noninfectious traumatic injuries, and how will the changes influence the treatment of these injuries?

Diagnostic Signs (1.1.1.2.4)-What observed physiological changes in response to the spacecraft environment can be used as diagnostic or predictive signs for impending deleterious conditions?

Preventive Treatments (1.1.1.2.5)-What treatments or procedures can be used to prevent deleterious conditions resulting from exposure to the spacecraft environment? (Chart 1-17 in Appendix A.)

Stress Tolerance Changes (1.1.1.3)-The analysis of changes in stress tolerances (Chart 1-16 in Appendix A) examined the environmental stresses associated with spacecraft design criteria, such as atmosphere composition, temperature, acceleration, radiation, toxic contaminants, noise, and vibration. While nominal and emergency limits for such stresses are generally well defined for terrestrial situations, the possibility of changed tolerances related to physiological alterations must be considered. The stresses considered in this phase of the analysis are:

Tolerance to Reduced Oxygen (1.1.1.3.1)-What changes occur in response and tolerance to reduced oxygen pressure in the spacecraft environment, and how will the changes influence the definition of the spacecraft atmosphere?

Tolerance to Increased CO_2 (1.1.1.3.2)-What changes occur in response to and tolerance of increased carbon dioxide pressures in the spacecraft environment, and how will the changes influence allowable carbon dioxide levels in the spacecraft atmosphere?

Tolerance to Diluent Gas Effects (1.1.1.3.3)-What effect will changes in the type and pressure of diluent gas have on respiratory phenomena and tolerance to evolved gas dysbarism, and how will these changes influence spacecraft atmosphere composition?

Acceleration Tolerance (1.1.1.3.4)-What changes occur in response and tolerance to acceleration, and how will the changes affect mission procedures related to the application of acceleration or gravitation?

Tolerance to Temperature Variation (1.1.1.3.5)-What changes occur in response and tolerance to temperature variations, and how will the changes influence the definition of the spacecraft thermal environment?

Exercise Tolerance (1.1.1.3.6)-What changes occur in response and tolerance to strenuous exercise, and how will the changes affect workload schedules during the mission?

Radiation Tolerance (1.1.1.3.7)-What changes occur in tolerance to radiation, and how will the changes influence the definition of radiation protective measures for the spacecraft?

Tolerance to Toxic Contaminants (1.1.1.3.8)-What changes occur in tolerance to toxic contaminants in the spacecraft atmosphere, and how will the changes influence allowable concentration levels for various contaminants?

Tolerance to Noise and Vibration (1.1.1.3.9)-What changes occur in the tolerance to noise and vibration and what protective action must be implemented?

Man-System Integration (1.1.2)-Man-System Integration is subdivided, as indicated in Section 2.2.1.2 and Chart 1-3 in Appendix A, into two subobjectives, one for Behavioral Research (Item 1.1.2.1) and one for Man-Machine Research (Item 1.1.2.2).

Behavioral Research (1.1.2.1)-Behavioral Research subobjectives were identified for the six subdivisions indicated in Chart 1-3 in Appendix A.

Individual Behavior (1.1.2.1.1)-Research on the behavior of individuals in the space crew consists of measuring human performance in specific, isolated simple responses, as opposed to complex, coordinated behavior (Chart 1-17 in Appendix A).

This area (1.1.2.1.1) was further subdivided into sensory, psychomotor, and cognitive behavior. Review of the literature indicated that this subdivision has wide acceptance. Sensory behavior subobjectives were further subdivided into five sense modalities (auditory, somesthetic, visual, orientation, and chemical sense); psychomotor behavior was subdivided into three subfunctions (perceptual motor functions, manipulation and control, and force production and control); and cognitive behavior was subdivided into three subfunctions (input, processing, and output functions).

Human Capabilities (1.1.2.1.2)-Research in human capabilities is concerned with complex behavior in which the various subdivisions of individual behavior are combined to produce practical tasks. This subobjective was further subdivided into operator, maintenance, and scientific investigation capabilities. These subobjectives are in accordance with the long-range interests of NASA, as indicated in the broad objectives. The behavior research included within human capabilities is considered basic and should be performed with as much control as possible. It should not be considered to consist only of "piggy back", noninterference observations in conjunction with operational experiments; it might require construction of specific artificial tasks to satisfy some of the subobjectives.

Group Structure and Dynamics (1.1.2.1.3)-Group structure and dynamics includes NASA objectives concerned with crew composition, crew activities, and relationships between flight crews and ground crews. This objective was further subdivided to examine group processes (communication, accommodation, and adaptation); group structure (role and authority relationships and group stability); and group attitudes (hostility, morale,and motivation). It is assumed that this research would be performed during observation of normal crew functions and using nonobtrusive techniques.

Personal and Social Adjustment (1.1.2.1.4)-The objective of evaluating personal and social adjustment is the identification of individual personality traits that produce successful adjustments in long-term space flight. This subobjective was further subdivided to specify individual personality traits (e.g., acquisitiveness, conservatism, masculinity); group-oriented personality traits (e.g., agressiveness, gregariousness); and socially oriented personality traits (e.g., altruism, loyality, desire for service). This research area will be primarily concerned with correlation between performance measures in orbit and personality variables identified before flight, and with the identification of any personality change occurring during flight.

Selection and Training (1.1.2.1.5)-Selection and training of crew members is addressed to the problem of determining how man's performance in space may be enhanced through crew selection, techniques for maintenance of skills, and efficient analysis of training requirements and training programs. Most of the critical issues developed in the analysis of this area will become part of other behavioral experiments. Specific training experiments will be addressed to skill retention and inflight evaluation of training equipment.

Performance Monitoring and Assessment (1.1.2.1.6)-Monitoring and assessment of performance are basic to success in all of the other Man-System Integration research studies. The subobjective for this area is to develop methods for monitoring performance and assessing proficiency that are accurate, efficient, and can be used unobtrusively so as not to influence the behavior of crew members being evaluated. This area was further subdivided into subobjectives aimed at direct measurement, indirect measurement, and subjective assessment.

Man-Machine Research (1.1.2.2)-Subobjectives were identified for the six subdivisions indicated in Chart 1-3 in Appendix A. Each of the six subobjectives was further subdivided into areas as indicated on the chart. The subobjectives within Man-Machine Research are hardware-oriented,as compared with those in individual behavior. Each subobjective examines man in relation to a specific type of onboard equipment.

Controls and Displays (1.1.2.2.1)-The objective of this subarea is the development and evaluation of design criteria for controls and displays with which crews of long-duration space missions must interface in performing system management, information processing, and vehicle navigation and control tasks. It is anticipated that this research will use controls and displays provided for the prime experiment mission. Considerable ground development and testing will have preceded the inflight evaluation. It is assumed, however, that additional selected prototype controls and displays will be furnished as a basis for separate experiments.

Locomotion and Restraint (1.1.2.2.2)-Locomotion and restraint is a continuing research area addressed to developing and evaluating techniques and equipment for astronaut restraint and locomotion, both inside and outside the spacecraft. This area includes techniques and equipment for crew and cargo transfer; assembly, maintenance, and repair; and mission operations.

Habitability (1.1.2.2.3)-Habitability includes equipment and procedures to make the crew's working and living areas comfortable and habitable

(Chart 1-20). For purposes of this analysis, life support and protective systems are not considered part of the habitability area. Habitability was subdivided into subobjectives concerned with crew space requirements (volume, configuration, living space, privacy); environmental requirements (illumination, noise, decor, color); and personal support requriements (hygiene, nutrition, recreation, sleep stations, health maintenance). Research considered in this area would be addressed to evaluating man's performance and his subjective responses to habitability features.

Work/Rest/Sleep Cycles (1.1.2.2.4)-The research on work, rest, and sleep cycles is concerned with obtaining more information about diurnal cycles and circadian rhythms in space, and with evaluating various schemes for scheduling work, rest, and sleep (Chart 1-20 in Appendix A). This subobjective was further subdivided into three areas: (1) rhythms and cycles, (2) sleep, and (3) work/rest. It is anticipated that this research will be developed for use on a noninterference basis.

Performance Aids (1.1.2.2.5)-Performance aids include equipment supplied for the enhancement of human performance in long-duration space missions (Chart 1-21 in Appendix A). The objective is to identify, develop, and evaluate performance aids in the areas of tools, force-assisting devices, remote manipulators, visual aids, and computer aids and checklists. Many of the critical issues developed in analysis of this subobjective will be incorporated in experiments that are prime under other areas, such as human capability and operations experiments.

Scheduling Techniques (1.1.2.2.6)-Techniques used in scheduling are addressed to the objective of developing and evaluating methods for constructing, modifying, and updating activity schedules for long-duration space research facilities.

Life Support and Protective Systems (1.1.3)-The objective for Life Support and Protective Systems was subdivided into subobjectives encompassing eight hardware areas (Items 1.1.3.1 through 1.1.3.8 below). This set of categories is consistent with that used in the Biotechnology Laboratory Requirements Study, Phases I and II, and was selected to include all hardware elements considered part of Life Support and Protective Systems. To reach a level of detail for which significant critical issues could be generated, it was considered necessary to subdivide the eight areas further. These subdivisions (Chart 1-4 in Appendix A) are delineated in the course of the following discussion.

Atmosphere Supply (1.1.3.1)-The objective of the Atmosphere Supply area (Chart 1-22 in Appendix A) is the development of technology for supplying the gaseous components of the spacecraft atmosphere, including storage of oxygen and diluent gas, oxygen recovery, and CO_2 reduction (Charts 1-29 through 1-37 in Appendix A). To identify critical issues for space experiments, this area was further subdivided into two-gas atmosphere supply, CO_2 reduction, electrolysis, and integrated oxygen recovery systems. Each of these areas has its own peculiar technology problems that need investigation in the space environment. In the case of atmosphere supply, most of the research problems are concerned with the behavior of gases and liquids under various storage and transportation conditions. In the case of CO_2 reduction, the primary research problem is evaluation of the relative advantages of various known techniques, i.e., Sabatier, Bosch, solid electrolyte, and molten carbonate reactors. Electrolysis technology problems center chiefly on the materials and properties of water electrolysis cells and upon the gas-liquid interface.

Atmosphere Purification and Control (1.1.3.2)-Purification and control of the atmosphere consists of the life support subsystem components designed to monitor atmosphere contamination, collect impurities from the atmosphere, and (in some cases) convert them to nonharmful or useful forms (Chart 1-23 in Appendix A). The objective for this area is to develop the technology for equipment required in atmosphere purification and control by (1) obtaining data on the behavior of the gaseous and liquid elements involved, (2) operating the components and subsystem elements in the space environment for a sufficient period, and (3) evaluating the relative effectiveness of various approaches to atmosphere purification and control. This area was further subdivided into carbon dioxide, trace contaminants, humidity, and aerosols, as shown on Charts 1-31 through 1-34 in Appendix A.

Thermal Control (1.1.3.3)-The objective is the development and evaluation of passive and active techniques for controlling temperature (Chart 1-24 in Appendix A). A logical subdivision of this area involves subobjectives addressed to passive versus active techniques for use in thermal control. Passive techniques are further subdivided into insulation and radiative surfaces (Chart 1-35 in Appendix A), and active techniques are subdivided into heating and cooling (Charts 1-36 and 1-37 in Appendix A).

Water Management (1.1.3.4)-The objective of the Water Management area is the development and evaluation of advanced technology for recovery of metabolic and wash water as well as excess water in the spacecraft atmosphere (Chart 1-25 in Appendix A). Analysis revealed that critical issues should be addressed to evaluation of various methods of water recovery, such as air evaporation, electrodialysis, vapor pyrolysis, vapor diffusion, vapor compression, multifiltration, and reverse osmosis. Since combinations of these approaches might be used in an integrated system, it is also necessary to derive critical issues for integrated water recovery subsystems. These considerations led to the subdivision of Water Management into storage and preservation (Chart 1-38 in Appendix A), reclamation (which was further subdivided into membranes and filtration-(Chart 1-25 in Appendix A), and phase change (Chart 1-39 in Appendix A).

Waste Management (1.1.3.5)-The Waste Management area has the objective of developing and evaluating the technology and equipment for collecting, processing, storing, and disposing of urine and fecal waste products (Chart 1-26 in Appendix A). It was found feasible to extract critical issues from the subdivisions indicated on Charts 1-52 through

1-55, and 1-78 in Appendix A.

Food Management (1.1.3.6)-The objective of the Food Management area is the development of technology for storing, preparing, and serving stored food as well as the processing and conversion of metabolic waste products into food (Chart 1-27 in Appendix A). Further subdivisions of this area are found on Charts 1-56 through 1-60 in Appendix A.

Crew Protective Systems (1.1.3.7)-Crew protection depends on the development of technology for space suits, back packs, gravity compensation, personal hygiene, fire protection, leakage, airlock operations, and aids for enabling the crew to perform necessary intravehicular activity (IVA) and extravehicular activity (EVA) tasks (Chart 1-28 in Appendix A). The critical issues can be identified from subdivisions indicated on Charts 1-19 through 1-22, 1-24 and 1-41 of Appendix A.

Engineering Experiments (1.2)-Subobjectives of the Engineering Experiments were identified for the subsystem areas shown in Chart 1-5 in Appendix A. The conduct of engineering experiments in space is a legitimate objective in the long-range space program, since it is necessary to qualify long-life subsystems in terms of performance, reliability, and maintainability before they are committed to long-duration space flights such as planetary missions. Although much testing can be performed on the ground in simulation facilities, it is evident that for some subsystems, valid tests can be performed only in space. The final evaluation of man's capability to operate and maintain these subsystems also requires the realistic environment of a space laboratory.

Each of the subsystem areas selected under Engineering Experiments either is required for manned space flight operations or else it involve man-machine interaction in its operation or maintenance.

Data Management Subsystems (1.2.1)-The objective the subsystems used for data management (Chart 1-42) is "to develop and evaluate advanced data management components and subsystems for long-duration space flight and to identify and develop techniques and equipment for onboard processing of experimental data, with emphasis on manned participation." This objective has been further subdivided into subobjectives covering nine interrelated areas:

1. Computers.
2. Specialized data processors.
3. Data collection.
4. Data retrieval.
5. Computer programs.
6. Extravehicular data transmission.
7. Onboard data transmission.
8. Temporary data storage.
9. Permanent data storage.

The process of subdivision into lower-level subobjectives was carried on until a level was reached at which critical-issue questions could be asked. It was found, for instance, that with specialized data processors, the next lower level (subdivided into converters, optical readers, personal calculators, multiplexing, automatic discriminators, and time generation) was sufficiently detailed to permit asking concise research questions.

Electrical Power (1.2.2)-As used in this study, electrical power (Chart 1-43) is the subsystem that provides, conditions, and distributes all electrical power to a manned space vehicle.

The objective in the analysis of the Electrical Power area was to evaluate advanced power components and subsystems and their man-machine interfaces to obtain data relative to advanced design criteria, crew performance requirements for operations and maintenance, and hardware performance in the space environment. Subobjectives were identified for solar cells, batteries, fuel cells, Brayton cycle supplies, Rankine cycle supplies, thermoelectric and thermionic supplies, nuclear heat sources, radiators, power conditioning, and power distribution.

As analysis proceeded in this area, it became evident that the critical issues identified as requiring space flight experimentation were solely concerned with the structural aspects of electrical power subsystems, and that answers to these critical issues would benefit all subsystems requiring space-deployable structures, in which large-diameter, dynamic space seals and bearings are needed, and in which gimbaling and orientation mechanisms are used. Therefore, the emphasis in this subarea encompasses structural subsystems such as deployable, expandable, extendable, and unfurlable structures required not only in electrical power subsystems, but also in those required for communications (deployable antennas), astronomy (extendable booms for telescopes), logistics (expandable airlocks and tunnels), and maintenance (expandable EVA shelters).

Stabilization and Control (1.2.3)-The objectives of Stabilization and Control (Chart 1-44) consist of (1) proving the feasibility of advanced equipment and techniques for spacecraft attitude stabilization and control, (2) obtaining advanced design criteria data (especially for associated controls and displays), and (3) verifying man's effectiveness in operating and maintaining advanced stabilization and control components and subsystems. Considered under this heading are the subsystems (concerned with spacecraft attitude, maintenance of artificial gravity, station-keeping, and pointing of sensors) whose inputs are primarily orientation data from onboard gyros and whose outputs are control signals to attitude control systems and servos.

Navigation and Guidance (1.2.4)-The objective of Navigation and Guidance (Chart 1-45) is the evaluation of advanced components and subsystems for spacecraft position sensing and tracking to obtain data on the feasibility of advanced components and subsystems, design criteria, and crew performance requirements. This subobjective includes the subsystem equipment and interfacing personnel concerned with determining space vehicle position with regard to such external features as stars and earth, and with maintaining or changing that position as required. The subsystem inputs include data on vehicle position relative to external features or space coordinates. The outputs are control signals.

Communication Subsystems (1.2.5)-The Communication Subsystems (Chart 1-46) include the spacecraft-borne hardware and supporting equipment required for communication from spacecraft to ground, spacecraft to spacecraft, and between elements within spacecraft. The objectives are to develop and advance the technology required for NASA's advanced manned orbital and planetary missions, to verify the feasibility of advanced communication components and subsystems, and to obtain data relevant to advanced design criteria and human performance requirements in the operation and maintenance of such systems.

Operations Experiments (1.3)-Operations Experiments (Chart 1-6) are essentially flight tests of various combinations of equipment, men, and procedures to verify that the complex can perform operational mission objectives and to identify problem areas where changes are necessary. The basic philosophy applied in analyzing this subdiscipline has been to assume that the operations experiments to be conducted are real, mission-related operations essential to the prime objectives of the particular space research facility.

Subobjectives for Operations Experiments were identified for the operation areas shown in Chart 1-6 in Appendix A. The subareas identified below were selected after careful analysis of NASA objectives.

Space Logistics and Resupply (1.3.1)-The objective of the logistic operations for long-duration, multimanned space missions (Chart 1-71) is the development and evaluation of techniques for cargo transfer (solids, liquids, and gases), personnel transfer, space rescue, and data return for long-duration space flight. Operations in this area require a complex interaction of flight crewmen and hardware, intimate ground-to-space interfaces, and extensive extravehicular activity.

Maintenance, Repair and Retrofit (1.3.2)-Long-duration space missions require maintenance, repair, and retrofit to achieve the necessary long life and the flexibility required to complete planned missions. The objective of this subarea (Charts 1-72 and 1-88) is to evaluate operational techniques for maintenance and repair activity, both inside and outside the spacecraft, and for retrofit, particularly that occasioned by updating of experiments. Manned space flight experiments can be used to maximum advantage only when the operational capability exists to make changes in experimental equipment as well as experimental procedures.

Assembly and Deployment (1.3.3)-The objectives of the Assembly and Deployment area (Chart 1-73) are the development and evaluation of an operational capability to perform assembly and deployment activities in space, to verify deployment and operation of lightweight space structures under actual operational conditions, to provide a technical base for design and development of large, expandable space structures, and to evaluate man's capability in support of deployment and alignment of large space structures. Subobjectives for Assembly and Deployment were derived separately and were then further subdivided as follows:

Assembly	Deployment
Positioning of modules	Erectable structures
Attachment of modules	Expandable structures
	Adjustment of elements
	Monitoring of deployment

Module Operations (1.3.4)-The Module Operations area (Chart 1-74) includes operations with separate experimental modules, whether attached to the space research facility or free-flying. The objective of this subdiscipline is to develop and evaluate methods for control, monitoring, connecting, and communicating with unmanned vehicles launched from a manned space vehicle or independently launched from the ground; and to develop and evaluate techniques for rendezvous and docking, remote control and manipulation, communication, and power.

Vehicle Support Operations (1.3.5)-Operations in support of the vehicle (Chart 1-75) have the objective of developing and evaluating techniques for onboard support of functions required in manned space flight missions, including habitability, flight plan maintenance, data management and computing, medical services, film processing, and vehicle control and stabilization.

2.2.1.4 Discussions with Non-Study-Team Authorities

Discussions were held with NASA Headquarters, Ames Research Center, Marshall Space Flight Center, and Manned Spacecraft Center personnel regarding the content of the analysis during meetings held in connection with the Biotechnology Laboratory Requirements Study (Reference 2-5).

2.2.1.5 Source Documents

The following list of documents includes a portion of those used as background data in the organized overview analysis and as sources against which critical issues were checked:

1. NASA Long-Range Plan for Aerospace Medicine, 15 June 1969.
2. Earth Orbital Experiment Program and Requirements Study, Scientific and Technological Objectives, Report No. L13-9852, NASA Langley Research Center, 28 July 1969.
3. Biomedical and Human Factors Requirements for a Manned Earth Orbiting Station, North American Aviation, Inc., Report No. SD 63-1392, 18 November 1963.

4. Experiment Program for Extended Earth Orbital Missions ("Yellow Book") NASA, 1 September 1969.

5. Space Research-Directions for the Future, Part Three: Space Science Board Study 1965. National Academy of Sciences, National Research Council, Washington, D.C., 1966.

6. Roth, R.M., Compendium of Human Responses to the Aerospace Environment, NASA CR-1205, Volumes I, II, and III, November 1968.

7. Busby, D. E., Clinical Space Medicine, NASA CR-856, July 1967.

8. Physiology in the Space Environment, Volumes I and II. National Academy of Sciences Publications 1485 A and B of 1967 and 1968.

9. Vinograd, S. P., Medical Aspects of an Orbiting Research Laboratory, Space Medicine Advisory Group Study, NASA SP-86, 1964.

10. Kail, L. T., Requirements Study for a Biotechnology Laboratory for Manned Earth Orbiting Missions, Volume I, NASA CR-1408, and Volume II, NASA CR-1409, August 1969.

11. Phase II of a Requirements Study for a Biotechnology Laboratory for Manned Earth Orbiting Missions, Vol. I and II, NASA CR 111794, October 1970 (McDonnell Douglas Astronautics Company - West, Report MDC G0620).

2.2.2 Critical Issues for Research

Critical issues identified as a result of the analysis described in Subsection 2.2.1 are listed in Table 1, Manned Space Flight Capability, in Appendix B under the subdiscipline headings. The critical issues are numbered with multi-decimal serial numbers corresponding to the numbering system of the organized overview.

2.3 ORGANIZED OVERVIEW ANALYSIS OF SPACE BIOLOGY

2.3.1 Overview of Objectives

A biological research program for an earth-orbiting research facility has been delineated as the result of establishing the information needs in the overview analysis; to resolve those needs in the several areas of biological investigation, instrument commonality was recognized. The combination of these factors will meet the NASA research objectives to define the influence of gravity and cyclical cues upon life processes. The research facility approach of providing a unique capability minimizes the costs of doing biological research in space and leads to an increased efficiency in facility utilization. The proposed investigations are oriented towards whole organism biology in that many items of interest, critical issues, are to be answered simultaneously. However, an individual investigator can be supplied data critical to his particular research. There must be assurance that the several interrelated factors were accommodated in the review processes. That assurance was found with the construction of a three-dimensional matrix. The three axes accounted for life processes, environmental factors, and test organism. Then, careful program and experiment definition obviates the performance of unrelated individual experiments.

2.3.1.1 Format of Overview Structure

The organized overview derived for biological research calls for the use of a three-dimensional matrix (Charts 2-1 in Appendix A). One axis, in accordance with the preceding discussion, is based on classical, philosophical concepts separating living things from nonliving things; that is, living things do the following:

1. Perform metabolic functions
2. Utilize energy
3. Respond to stimuli
4. Reproduce themselves
5. Possess definite cellular and structural organization

Metabolism has been divided into three separate categories: the biosynthetic or anabolic processes (Chart 2-3), the breakdown or catabolic reactions (Chart 2-5), and the mechanisms that control these processes (lower half of Chart 2-4). The anabolic processes were further categorized by function, i.e.. the ultimate use that the biosynthesized material will serve. In nature, the anabolic processes are used to build energy storage units composed of carbohydrates, protein, and lipids; to building structural elements such as bone and muscle; and to synthesize the regulatory elements that control the living functions. Catabolism is divided into categories based on the nature of material being metabolized: proteins, carbohydrates, lipids, and polynucleotides. The control mechanisms were separated into the functions governed by hormonal action and the functions that are genetically regulated.

Energy-yielding reactions have been categorized into reactions requiring light (photophosphorylation) and those not requiring light. Photophosphorylating reactions were then divided into photosynthetic and chemosynthetic reactions. The nonphotophosphorylating reactions are more prevalent in nature and therefore were divided into several component reactions. The primary distinguishing characteristic is whether a reaction requires oxygen. The aerobic processes were then categorized by the pathway of intermediate metabolism in which the energy-yielding reaction is found. The most common anaerobic energy-yielding reaction occurs in the glycolytic pathway of carbohydrate metabolism. Other fermentative, energy-yielding reactions occur infrequently in nature and are employed only by specific organisms; for this reason, they have been grouped together as a single unit.

All living things respond to stimuli. Stimuli responses which have been considered in this expansion are rhythms and tropisms. Other stimuli-response relationships will be examined in the physiological response of organs/organisms. The rhythmic processes (circadian, lunar, annual, etc.) and the physiological mechanisms associated with them will be studied. The other major category is confined to tropic responses, in which gravity, light, etc., provide the stimulus; the morphological as well as physiological response of the organism is to be measured.

The fourth characteristic separating living from nonliving organisms is reproduction. The philosophy employed in this area was to separate reproduction into the study of the developmental process, from embryogenesis to the formation of a mature adult and the study of genetics, information exchange and storage. The final characteristic of life to be considered in organization. This area was divided into two subunits, physiological organization and behavioral organization. The physiological organization was further subdivided into areas related to the organ systems. Each of these subsets was in turn categorized into meaningful divisions until the critical areas could be defined. Behavioral organization was simpler, in that this category was organized into the six principal subsets of behavior: sensation, perception, learning, memory, motivation, and emotion.

The second axis of the matrix is a taxonomic classification of living organisms. Viruses have been included in spite of the controversy concerning their animate versus inanimate nature. Viruses are associated with many plant and animal diseases and therefore warrant study. Studies of some forms of life have been deliberately expanded in a more detailed fashion than others, since it is likely that some animals, where extrapolation of results to man can be made with greater confidence, will be of greater interest to the scientific community. It is likely that mammals, for example, will be studied in greater detail than worms. Similarly, the spermatophytes, because of their economic importance, are more likely to be studied than the bryophytes.

The third axis of the matrix, which lists the environmental factors, will need no further subdivision. Weightlessness and the possible combined effects of weightlessness with other factors are the main parameters that will be studied.

2.3.1.2 Rationale for Subdivision of Objectives

The logic behind the expansion scheme is to provide a mechanism in which an orderly progression of experimental observations can be established. The more general questions proceeding the specifics; for example, it should be determined whether a particular environmental factor influences respiration before examining the particular energetic reactions associated with the respiratory processes. Through this method, it is possible not only to identify meaningful areas of investigation, but also to anticipate the parameters to be measured and the instrumentation required to perform these measurements.

The critical issues arising from the analysis have been coded to correspond with appropriate items in the organized overview chart. Table 2 of Appendix B lists the critical issues of Space Biology.

2.3.1.3 Discussions with Non-Study-Team Authorities

Non-study-team authorities with whom the study team conferred included the following:

Dr. T. Jahn	Zoology Department University of California at Los Angeles Los Angeles, California
Dr. R. Lindberg	Northrop Corporate Laboratories Hawthorne, California
Dr. J. P Meehan	Human Centrifuge and Environmental Physiology Laboratories School of Medicine University of Southern California Los Angeles, California
Dr. N. Pace	Environmental Physiology Laboratory University of California Berkeley, California
Dr. C. Pittendrigh	Department of Biology Stanford University Palo Alto, California
Dr. J. Spizizen	Scripps Institute of Oceanography LaJolla, California
Dr. K. Yokoyama	NASA-Ames Research Center Moffett Field, California

The consensus derived from the study team - non-study-team conferences was that the methodology employed was valid. Moreover, the series of reviews of the matrix and the overview charts covering the life processes verified their accuracy and assured the comprehensiveness of the subject matter.

One suggestion that the study team was unable to accommodate was a single matrix for "whole animal biology." This was omitted after lengthy consideration, primarily on the basis of the experimental approach.

2.3.1.4 Source Documents

The NASA objectives for Space Biology as outlined in Earth Orbital Experiment Program and Requirements Study, Scientific and Technological Objectives (Report No. L13-9852, NASA Langley Research Center, 28 July 1969) were used as the primary source document for Task 1 to assure responsiveness of the program to NASA's overall goals. The NASA Functional Program Elements for Space Biology, as outlined in Candidate Experiment Program for Manned Space Stations (NASA document No. NHB 7150 XX, 15 September 1969) were reviewed in detail, as was the American Institute of Biological Sciences (AIBS) Final Report to NASA dated

December 1967. Biological questions proposed for investigation in space were compiled from each of these sources, tabulated, and arranged in outline format to facilitate easy usage. This compilation served as an input to the organized overview analysis, and care was taken to include all suggestions in the present work.

2.3.2 Critical Issues for Research

Critical issues identified as a result of the analysis described in Subsection 2.3.1 are listed in Table 2, Space Biology, in Appendix B under the subdiscipline headings. The critical issues are numbered with multidecimal serial numbers corresponding to the numbering system of the organized overview.

2.4 ORGANIZED OVERVIEW ANALYSIS OF SPACE ASTRONOMY

2.4.1 Overview of Objectives

For the purposes of this study, astronomy is defined as the study of the universe by remote sensing of radiations from the objects and phenomena that the universe contains. The discipline is concerned with such things as planets, stars, galaxies, the diffuse matter and fields between them, and less-well-understood objects such as x-ray sources and pulsating radio sources (pulsars). Cosmic rays, gamma rays, and gravitational radiation are treated here and in Space Physics. Wherever it is clear that other scientific disciplines have superior capabilities to attack problems associated with astronomical bodies, as in the case of geological or chemical studies of the lunar surface, these problems are generally excluded from Space Astronomy.

2.4.1.1 Major Subdiscipline Divisions

Astronomy is concerned with increasing man's knowledge and understanding of the universe, thus, in Chart 3-1 in Appendix A, the first subdivision of Space Astronomy (3.0) was into Knowledge (3.1) and Understanding (3.2) branches. The Knowledge branch was conceived to accommodate subject matter relating to observations, and the Understanding branch is intended to accommodate theoretically inspired subject matter. The subject matter of the Knowledge branch tends to emphasize objects and their physical properties, whereas the material in the Understanding branch relates more to processes and mechanisms.

Both major branches of the Space Astronomy overview were next divided into an object hierarchy in which lower levels correspond to smaller subdivisions or units of the universe.. To some extent, the increasingly higher levels correspond to increasing distance of the objects in question from Earth. Some currently interesting astronomical objects cannot be readily placed in the type of hierarchical arrangement adopted here, so in order to include them, an "unclassified" category was added that is independent of levels. Examples of "unclassified" objects are the discrete X-ray sources, some of which may be extragalactic, while others may be located within the galaxy.

2.4.1.2 Rationale for Subdivision of Objectives

The basic feature of the overview subject subdivision is a breakdown of ea subject into itself as a whole plus its natural (or obvious or recognized) constituents. In some cases, e.g., star clusters, the as-a-whole category is replaced by the system of the subjects in point. Thus, every element of the overview chart is one of the following:

1. The subject as a whole or a system of like objects.
2. Independent parts of the subject or constituents of the subject.

For convenience in grouping and to achieve some continuity and generality, certain generic terms have been adopted as labels of some overview entries, e.g., "ensemble" (meaning cluster, group, or aggregate), "discrete", and "diffuse" (usually observationally defined).

At the lowest levels of the overview structure, the Knowledge branch proceeds in some cases to properties of the finest meaningful phenomenological units (e.g., the temperature distribution in the solar chromosphere). The corresponding levels of the Understanding branch, on the other hand, generally have as elements models or theories relating to objects, their parts, properties, processes or mechanisms.

2.4.1.3 Discussions With Non-Study-Team Authorities

A brief round of discussions with non-study-team authorities included Drs. R. G. Stone, K. L. Hallam, and D. West of NASA-Goddard; and Dr. J. Findlay, Director of the National Radio Astronomy Observatory. These discussions occurred at about the halfway point in the development of the organized overview in Space Astronomy, when the general nature of the charts had been established, and a number of charts detailing the structure to the lowest levels were available for examination. The discussions led to the inclusion of additional critical issues related to very-low-frequency radio-wave emissions, the nearer galaxies, and millimeter-wavelength observations of the cosmic microwave background and of planetary emission.

2.4.1.4 Source Documents

The principal reference documents utilized in the Space Astronomy section of this study were:

1. A Long Range Program in Space Astronomy (position paper of the Astronomy Missions Board),ed. Robert O. Doyle, NASA Publication SP-213, July 1969.
2. Orbital Astronomy Support Facility Study, Douglas Missile and Space Systems Division Report DAC-58142, Volumes II and III, June 1968.

In addition, a large number of journals, review papers, and space astronomy planning documents were consulted from time to time. Bibliographic information on those cited is given in later subsections of this report.

2.4.2 <u>Critical Issues for Research</u>

Critical issues identified as a result of the analysis described in Subsection 2.4.1 are listed in Table 3, Space Astronomy, in Appendix B under the subdiscipline headings. The critical issues are numbered with multidecimal serial numbers corresponding to the numbering system of the organized overview.

2.5 ORGANIZED OVERVIEW ANALYSIS OF SPACE PHYSICS

2.5.1 <u>Overview of Objectives</u>

2.5.1.1 Major Subdiscipline Divisions

The organized overview analysis of the Space Physics discipline was accomplished by dividing the discipline into two major areas based on two types of investigations. In the first area, developed under the question, "What measurements or experiments can be conducted in physics that take advantage of the unique characteristics of the space environment?", the research objectives are based on using space as a physics laboratory and can be referred to as physics <u>in</u> space.

The second area was a development of what has normally been recognized as space physics under the question, "What are the present state and principles of order and change that describe the space environment?" This latter area can be referred to as physics <u>of</u> space.

The two broad areas of investigation above are basically different from each other in content and therefore have been analyzed using two different structuring methods. For the area of Physics Experiments Utilizing Space, the breakdown is based on the disciplines of physics, while the Physics of the Space Environment is based on a geographical approach; i.e., the solar system was broken down into its component parts, which were then subdivided, and so forth.

2.5.1.2 Format of Overview Structure

All areas of investigation in Space Physics have been included in the overview. It was recognized at the start that many areas in all probability could not be fruitfully investigated in space. Leaving such areas out of the breakdown, however, was judged unwise for two reasons. First, it is impossible when starting to analyze a particular area to be assured that no questions will be developed that can utilize the environment of space. Second, the existence of such a chart for reference will indicate to the physicist and to the planners of space activities which areas may be receiving insufficient attention. Thus, experts in these neglected areas could be asked to analyze their areas to develop critical issues, answers to which might indeed require experimentation in the space environment.

Under the broad question of "What measurements or experiments can be conducted in physics to take advantage of the unique characteristics of the space environment?", six specific realms of physics were listed:

1. Classical Mechanics, Relativity, and Gravitation (Chart 4-2).
2. Electromagnetism (including Optics) (Chart 4-4).
3. Heat, Thermodynamics, and Statistical Mechanics (Chart 4-5).
4. Deformable Bodies (Chart 4-7).
5. Atomistic Structure of Matter (Chart 4-1).
6. Plasma Physics (Chart 4-13).

This listing of areas is somewhat arbitrary, but it appears to represent a conventional delineation of subjects.

The treatment of plasma physics as a separate subdiscipline was based on two factors. First, plasma physics is derived not only from electromagnetic theory; it has just as strong a basis in statistical physics, with additional roots in atomic and molecular physics as well as other areas. Second, plasma physics is currently one of the primary areas of investigation in physics, and as such, it can quite naturally be represented as a separate subdiscipline in an overview.

The second major subdivision of Space Physics, "What are the present state and principles of order and change that describe the space environment?", can be structured quite naturally into three subdivisions: a direct investigation of the local space environment, an interpretation of data from remote environments through local experimentation, and investigations of remote environments using remote sensing techniques. Investigations performed with remote sensing encompass the realm of astronomy and thus have only been noted for the sake of completeness in this discussion. Of the other two, the first, "What are the present state and principles of order and change that describe the local space environment?", represents almost all of the past and current Space Physics investigations.

In the course of the overview analysis, it became apparent that a third major heading was warranted under Space Physics, Spacecraft Environmental Conditions. In a sense, this is not a proper heading under Space Physics; rather, it may be regarded as a composite of such contamination questions as plasma perturbations and spacecraft thermodynamics. The questions developed under this heading could logically be placed throughout the body of the overview. While such organization would be logically consistent with the rest of the development, the area of spacecraft environmental interaction is of interest in its own right and has therefore received special treatment.

2.5.1.3 Rationale for Subdivision of Objectives

In developing the organized overview for Space Physics, four areas of investigations were identified by NASA for special emphasis:

1. Physics and chemistry laboratory.
2. High-energy particle physics and cosmic rays.
3. Plasma physics.
4. Relativity and gravitation.

<u>Physics and Chemistry Laboratory</u>-To facilitate the analysis of this area, it was studied as a composite of two research disciplines: fluid dynamics and material science. The questions related to fluid dynamics are found in two of the disciplines of physics, Deformable Bodies and Thermodynamics. Those related to material science fall under Solid State Physics and Thermodynamics.

The questions developed for a physics and chemistry laboratory can be structured according to whether the objective to be served is primarily scientific or technological in nature. With little exception, only those questions that are of a fundamental or scientific nature were carried through the entire study. Other questions normally were included in the Manned Space Flight Capability discipline or as supporting technology development items. One exception is in the area of research leading to materials that are now unavailable but are required to conduct physics experiments (for example, high-purity materials). Development of experiments to produce these materials is included in the study.

High-Energy Particle Physics and Cosmic Rays-The issues developed for the high-energy cosmic ray laboratory are derived from two different types of investigations. The first uses the cosmic rays present in space as a particle beam for studying the properties of high-energy reactions. This is classed under utilizing space as a physics laboratory. The second type of investigation is the study of cosmic rays themselves. This comes under the physics of the space environment. Before cosmic rays can be used to fullest advantage as a particle beam, however, their properties should be well known.

Relativity and Gravitation-The area of relativity and gravitation is unique. The questions are of such fundamental importance and general interest to science that a great deal of study has been going into possible experiments that could verify general relativity theory. As a result of this interest, very little development was necessary in this area of the overview analysis. In subsequent study work, however, special emphasis was placed on the possible use of man as an aid in performing the experiments.

Plasma Physics-For the most part, the disciplines of physics are well defined, as evidenced by the general uniformity in content of the various texts dealing with a given subject. With plasma physics, such is not the case. The topics in this area are varied, as are the theoretical and experimental techniques required to investigate them. For example, understanding the mechanisms of collisionless shocks, such as the earth's bow shock could be included under both Physics of the Space Environment and Plasma Physics Experiments Using Space. (i.e. "Laboratory" plasma physics). This type of experiment was arbitrarily placed under Physics of the Space Environment. The plasma physics and environmental perturbations studies aim at satisfying objectives that have been developed in four different areas of the overview: Plasma Physics, Ionosphere, Magnetosphere, and Spacecraft-Environment Interaction.

The critical issues for Plasma Physics fall into four different areas of experimental investigation:

1. Observation and measurement of the space environment to determine the plasma configuration of the environment.

2. Increase of knowledge of space phenomena through controlled perturbation of the environment.
3. Investigation of vehicle interactions with the space environment.
4. Use of the unique plasma conditions of space to conduct experiments that will validate theoretical plasma calculations.

The point of view taken in this study is that active use of the space environment for laboratory plasma physics experiments (area 4 above) must await the more complete definition of the environment (areas 1, 2, and 3).

Physics of the Space Environment

The division of the question, "What are the present state and principles of order and change that describe that portion of the space environment that is accessible to local sensing" (Item 4.2.1 in Chart 4-1), was based on the three dominant features of the solar system: the sun, the large solid bodies in the system, and the interplanetary medium. The distinction between the large solid bodies and the solid particles in the interplanetary medium has been made on the basis of the strength of the gravitational force on the body in comparison with other forces on the body; hence the heading Satellites of the Sun. The only overlap occurs with meteoroids, the larger of which are dominated by gravity and the smaller by radiation pressure and other effects. Since asteroids and comets fall under satellites of the sun, meteoroids were placed under the interplanetary medium.

2.5.1.4 Discussions With Non-Study-Team Authorities

Contacts in the four major areas developed in space physics were made as follows:

1. High-Energy Particles and Cosmic Rays
   Dr. Donald Hagge, Manned Spaceflight Center, Houston
2. Materials Science
   Prof. John Hudson, Rensselaer Polytechnic Institute
3. Relativity and Gravitation
   Dr. John Estabrook, Jet Propulsion Laboratory
4. Plasma Physics
   M. C. Trichel, Manned Spaceflight Center, Houston

The meetings with these scientists were devoted primarily to review of the critical issues developed in the overview analysis and to some discussion of the possibility of utilizing space for the investigations suggested by these issues. In the course of these discussions, it was suggested that all questions related to surface chemistry and physics should be eliminated from further consideration for space research. The vacuum of space in the vicinity of a spacecraft is neither hard enough nor clean enough for experimentation in this area, and the problems of surface preparation would exist independently of the experimental site. It was also pointed out that for high-energy particle experiments to be successfully carried out in space, the properties of the cosmic ray beam should be understood.

2.5.1.5 Source Documents

Two types of sources were used in accomplishing the overview analysis. Many textbooks in physics were used in developing the upper levels of the overview, both as guides to the subdivisions and to ensure completeness in the overall development. These are listed in Group 1 below. The critical issues were developed with the aid of the documents listed in Group 2.

Group 1

<u>Handbook of Physics</u>, Condon, E. W., and Odishaw, H., 2nd edition, McGraw Hill, 1967.

<u>Classical Mechanics</u>, Goldstein, H., Addison-Wesley Publishing Co., 1950.

<u>Mechanics</u>, Slater, J. C., and Frank, N. H., McGraw Hill, 1947.

<u>Classical Mechanics</u>, Corben, H. C., and Stehle, P., 2nd edition, John Wiley and Sons, Inc., 1960.

<u>Gravitation and Relativity</u>, Chiu, H. Y. and Hoffman, W. F., W. A. Benjamin Inc., New York, 1964.

<u>Classical Theory of Fields</u>, Landau, L. D., and Lifshitz, E., 2nd edition, Addison-Wesley Publishing, Co., 1962.

<u>Electromagnetism</u>, Slater, J. C., and Frank, N. H., Dover Publishing Co., 1969.

<u>Electromagnetic Theory</u>, Stratton, J. A., McGraw Hill, 1941.

<u>Static and Dynamic Electricity</u>, Smythe, W. R., 3rd edition, McGraw Hill, 1968.

<u>Hydrodynamics</u>, Lamb, H., 6th edition, Dover Publishing Co., 1932.

<u>Treatise on the Mathematical Theory of Elasticity</u>, Love, A. E., 4th edition, Dover Publishing Co., 1927.

Applied Elasticity, Prescott, J., Dover Publishing Co., 1924.

Structure of Matter, Finkelnburg, W., Academic Press, Inc., 1964.

The Atomic Nucleus, Evans, R. D., McGraw Hill, 1955.

Atomic Physics, Born, M., 7th revised edition, Hafner Publishing Co., 1961.

Atomic Spectra and Atomic Structure, Herzberg, G., 2nd edition, Dover Publishing Co., 1944.

Textbook of Nuclear Physics, Smith, C. M., Pergamon Publishing Co., 1964.

Proceedings of the 13th International Conference on High-Energy-Physics, University of California Press, 1967.

The Plasma State, Hellund, E., Reinhold Publishing Co., 1961.

Introduction to Solid State Physics, Kittel, C. F., 2nd edition, John Wiley and Sons, Inc., 1956.

General Relativity and Gravitational Waves, Weber, J., Interscience Publishing, Inc., 1961.

Group 2

Objectives and Goals in Space Science and Applications-1968, prepared by the Office of Space Science and Applications, Office of Technology Utilization, NASA, 1968.

A Satellite Wake Region as an Ultrahigh Vacuum Chamber, Case 105-3, Kostoff, R. N., Bellcomm, Inc., 6 May 1969.

Cosmic-Ray and High-Energy Physics Studies in Space, TR-69-103-1, Kaufman, L., Bellcomm, Inc., 1 April 1969.

The Uses of Manned Space Flight Space Physics Research, Grobman, W. D., Hilberg. R. H., and Kaufman, L., TM-69-1015-2, Bellcomm, Inc., 20 February 1969.

An Approach Toward the Implementation of a High-Energy Physics and Cosmic-Ray Facility in Space, TM-69-1015-4, Kaufman, L., Bellcomm, Inc., 25 July 1969.

Physics of the Earth in Space-A Program of Research: 1968-1975, National Academy of Sciences, National Research Council, Woods Hole, Mass., 1968.

Draft, Candidate Experiment Program for Manned Space Stations, NASA NHB 7150.XX ("Blue Book") 15 September 1969 including the following:

Space Physics Airlock Experiments, FPE 5.6.

Plasma Physics and Environment Perturbation, FPE 5.7.

Cosmic Ray Physics Laboratory, FPE 5.8.

Remote Maneuvering Subsatellite, FPE 5.12.

Materials Science and Processing, FPE 5.16.

Contamination Measurements, FPE 5.17.

Exposure Experiments, FPE 5.18.

Fluid Physics in Microgravity, FPE 5.20.

Physics and Chemistry Laboratory, FPE 5.27.

Physics and Astronomy Programs, Mitchell, J. L., NASA Office of Space Science and Applications.

Environmental Modification Experiment in Space, Tidman, D. A., et al, The Institute for Fluid Dynamics and Applied Mathematics, University of Maryland, March 1968.

Manufacturing Technology Unique to Zero-Gravity Environment, Marshall Space Flight Center, 1 November 1968.

Earth Orbital Experiment Program and Requirements Study, Scientific and Technological Objectives, Report No. L13-9852, NASA Langley Research Center, 28 July 1969.

ORL Experiment Program, Volume B, Part XIII, "Physical Sciences," Federal Systems Division, IBM Corporation, February 1966.

"The Optical Environment of Manned Spacecraft," Newkirk, G., Planetary Space Science, 15, p 1267 (1967).

Space Research-Directions for the Future, Space Science Board, Woods Hole, Mass., 1965.

A Proposal for a High-Energy Cosmic-Ray Physics Program, Bandi, R. D., et al., Cosmic-Ray Physics Section, Manned Spacecraft Center, Houston, Tex., January 1968.

Uses of Manned Space Flight for Materials Science and Processing In Space, NASA TM-69-1015-3, 21 March 1969.

Space Physics Position Paper, NASA Space Physics Planning Panel, 15 August 1969.

Experiment Program for Extended Earth Orbital Missions ("Yellow Book") Volumes I and II, Revised September 1969.

On the Significance of TR-69-103-7-3 for Present NASA Plans for a Cosmic-Ray and High-Energy Physics Facility, Kaufman, L., Bellcomm, Inc., 10 September 1969.

Evidence for the Existence of New Processes at Energies above 2 x 10^{11} eV, Bellcomm, Inc., 10 September 1969.

Space Processing and Manufacturing Meeting, Marshall Space Flight Center, 21 October 1969.

Meteoroid Environmental Mode, 1969 (Near-Earth to Lunar Surface), NASA SP-8013, March 1969.

2.5.2 Critical Issues for Research

Critical issues identified as a result of the analysis described in Subsection 2.5.1 are listed in Table 4, Space Physics, in Appendix B under the subdiscipline headings. The critical issues are numbered with multidecimal serial numbers corresponding to the numbering system of the organized overview.

2.6 ORGANIZED OVERVIEW ANALYSIS OF COMMUNICATIONS AND NAVIGATION

2.6.1 Overview of Objectives

2.6.1.1 Major Subdiscipline Divisions

Chart 5-1 of Appendix A gives an abbreviated representation of the organized overview in communications and navigation. The chart illustrates the major subdiscipline division and serves as an indication of the nature of the detailed analyses. Consideration is limited to the use of space technology to fulfill the need for information exchange and for control and coordination of vehicles over long distances.

A fundamental difference between research in communications and research in navigation and traffic control is exposed in the basic questions at the top of each of these areas (Items 5.1 and 5.2, Chart 5-1). For communications, the question implies growth and augmentation of an existing, mature, and highly structured field. For navigation and traffic control, the question implies that the rapidly expanding use of high-speed transportation has defined a new service area where problems and services are only partially fulfilled at the present. When the problems of navigation and traffic control are better understood and when more progress has been made toward their solution, this field could possibly be merged with communications because of their common features of technology and research objectives. In the present analysis, however, the separation has been maintained because of the complexity and novelty of the field of traffic control.

The central theme of the derivation of the overview outlined in Chart 5-1 may be framed in the following series of questions:

1. Who are the users and how may they be categorized?
2. What services are required for, or desired by, these users?
3. How may space technology provide these services?
4. Can decisions be made as to the best system approach?
5. Is the required technology available?
6. Is sufficient information available for engineering design?

Answers to all of the questions may not be required in a given line of development, and subjective judgment has frequently been employed in disposing of certain aspects of the problem. Substantial overlapping of objectives was anticipated and has been observed.

Since the principal purpose of this study is to define experiment requirements, particularly for execution on manned space stations, it is appropriate to review the general nature of communication and navigation experiments that are required, or may be required, to fulfill primary and secondary objectives. Such objectives may be grouped within the following major categories:

1. Measurements of the Space Environment-Although much knowledge has been obtained of the environment within which elements of space communication systems must operate, the available knowledge is still inadequate for the design of the advanced systems of the future. Such environmental measurements include the following:
   A. Noise Measurements-Ambient noise measurements at all frequencies that may be employed by space communication systems. Such measurements should include observations by both earth-observing and space-observing antennas.
   B. Ionization Density-The density of ionization at the spacecraft can influence the breakdown of high-voltage components and antennas. Of particular interest is the time history of ionization following solar flares.
   C. Micrometeorites-High confidence in collision probability and material erosion rates will be required for design of reliable, long-life components. For example, it would be helpful if all spacecraft were instrumented for micrometeorite collision observations.
2. Technology Demonstration in Space-As new devices are developed, it will be necessary to demonstrate them in space, particularly where the space environment is essential to their operation (e.g., deployable, flexible structures designed for zero gravity). Such experiments may also play an integral part in space qualification of new components.

3. Measurements of System-Environment Interaction — To be most meaningful, measurements of the environment should have minimum perturbing influence on the environment. However, an operational system will usually interact with and influence the environment. Material outgassing will cause an increase in pressure, even in a well-vented system. Large structures will perturb the flow of solar wind, perhaps causing a local increase in ionization density. Test vehicles for new components or subsystems should also be instrumented for environmental effects to assist in interpretation of performance data.

4. Demonstration of Concept Feasibility-The choice between system concepts or the decision to implement a system approach frequently depends on a realistic system simulation. Since the geometry of space communications is difficult to simulate in the laboratory, a demonstration with existing satellites (such as the ATS series) may be the most meaningful. The manned earth-orbiting vehicles offer great potential for such demonstrations. Modular assemblies can be configured for such space demonstrations even though the precise time-phasing of experiments was not examined in the study.

5. Initial Operational Demonstration-Many of the concepts for which space communication systems appear to offer advantages require interfaces with very complex ground systems. Demonstration of such systems may require iterative software development or evolutionary development of terrestrial networks. A highly flexible space component may be very desirable for the evolutionary growth of such systems.

Of the five groupings listed, it may be noted that space environment measurements consist of basic observations and have much in common with the Space Physics discipline. The remaining four groups may be described as engineering demonstrations and instrumentation measurements. System-environment interaction measurements are necessary to check out mathematical models employed in the design of hardware for the space environment and to provide new empirical data required in engineering design. Although not primarily scientific in nature, data from such experiments should be carefully screened, since deviations from theoretical predictions may indicate the presence of unknown phenomena.

The feasibility demonstration experiments are perhaps most difficult to specify at the present time, although general statements on component characteristics may be made from knowledge of system requirements (i.e., net configuration, number of subscribers, terminal size, geographical deployment, data rate per user, data resolution, etc.) for the many possible systems for which it may be desirable to evaluate system concepts.

Two current examples of initial operation-demonstration experiments are available. The ATS-F satellite with its 30-foot antenna will be employed to demonstrate TV broadcasting to communities in India, and the ATS-1 was designated for initial satellite link demonstration for the biomedical information network. From such experiments, operational performance may be demonstrated, and the specifications for both the space and user terminal components of operational systems may be developed. To achieve an operational system for both of these requirements, substantial development is required on the ground elements of the system, since the major cost of system procurement will be in the user terminals. Operational experience will provide valuable inputs to such development.

2.6.1.2 Format of Overview Structure

The complete overview structure to the level of critical issues is contained in Appendix A in Charts 5-2 through 5-6 for Communications and in Charts 5-7 through 5-9 for Navigation and Traffic Control.

Under Communications, the major divisions are Applications (Item 5.1.1, Chart 5-2), Research and Development (Item 5.1.2, Chart 5-3), and Resource Management (Item 5.1.3, Chart 5-6). Under Applications, the selected subdivisions are Space Mission Support (Item 5.1.1.1), Broadcast (Item 5.1.1.2), Information Network (Item 5.1.1.3), Data Collection (Item 5.1.1.4), and Service Requirements (Item 5.1.1.5), all on Chart 5-2. In Research and Development, the subdivisions are Theory (Item 5.1.2.1), Environment (Item 5.1.2.2), Propagation (Item 5.1.2.3), and Technology (Item 5.1.2.4), all on Chart 5-3. The division of Resource Management is intended to include those NASA activities that are not necessarily related to direct research or hardware but may more appropriately be described as consultative or are performed cooperatively with other government agencies. Subdivisions include Frequency Allocation (Item 5.1.3.1), Millimeter Wave Demonstration (Item 5.1.3.2), Optical Frequency (Item 5.1.3.3), Future Needs (Item 5.1.3.4), and Usage and Control (Item 5.1.3.5), all on Chart 5-6.

Major divisions under Navigation and Traffic Control describe the services to be provided for general categories of users. These categories are Space Needs

(Item 5.2.1), Aircraft and Marine Needs (Item 5.2.2), and Space Vehicle Launch and Reentry Needs (Item 5.2.3), on Charts 5-7, 5-8, 5-9. Under Space Needs, the major subdivisions are Earth-Oriented Systems (Item 5.2.1.1) and Autonomous Navigation Systems (Item 5.2.1.2), both on Chart 5-7. This subdivision separates candidate systems requiring observations made onboard only from those that require cooperation by or observations of earth-referenced transmitters or satellites. The divisions under Aircraft and Marine Needs are primarily the various services to be provided, i.e., Navigation (Item 5.2.2.1), Surveillance (Item 5.2.2.2), Collision Avoidance (Item 5.2.2.3), Enroute Communications (Item 5.2.2.4), and Search and Rescue (Item 5.2.2.5), all on Chart 5-8. The problems of concern under Space Vehicle Launch and Reentry Needs are those that potentially may be created by intrusion of space vehicles into the operating areas employed by terrestrial transportation vehicles. Subdivisions are Aerospace Clearances (Item 5.2.3.1), Local Traffic Control (Item 5.2.3.2), and Corridor Safety (Item 5.2.3.3), all on Chart 5-9.

2.6.1.3 Rationale for Subdivision of Objectives

The detailed rationale for selection of many of the lower-level subdivisions and critical issues in the Communications and Navigation organized overview is included as an integral part of the tabulation of the Communications and Navigation critical issues. These critical issues and the explanations of rationale are presented in Table 5 in Appendix B.

2.6.1.4 Discussions With Non-Study-Team Authorities

Beginning with contractor orientation meetings at Langley Research Center at the outset of the study, the study team obtained inputs from non-study-team authorities in areas of importance to the planning of Communications and Navigation space experiments. As the organized overviews were developed and the critical issues were derived, visits were made to selected individuals and agencies, mostly within NASA. At these meetings, the philosophy as well as the results of the overview were presented, and an appraisal of the work was received. The results of these conferences formed the basis of the study team's high confidence in the comprehensiveness and general acceptability of the organized overview and the resulting critical issues.

The non-study-team authorities contacted in the Communications and Navigation disciplines are listed below.

NASA Headquarters

Dr. R. Marsten, Director, Communications Programs, OSSA

Mr. J. Rosenberg, Deputy Director

Mr. D. Rogers, Advanced Programs, Communications

Mr. E. Ehrlich, Chief, Navigation and Traffic Control

Dr. A. M. G. Andrus, Chief, Communications Programs

Mr. R. Gutheim, Technical Assistant, Advanced Programs, OSSA

GSFC

Mr. S. Gubin, Communications and Navigation Applications

Mr. C. Laughlin, Navigation Systems

Mr. R. Pickard, Communications Systems

ERC

Mr. L. Keane, Chief, Communications and Navigation Satellite Programs

Dr. A. E. Barrington, Chief, Electromagnetics Division

Dr. J. Eckerman, RFI Measurements

Mr. J. Hill, Optics

Mr. B. Goldstein, Communications Technology

Mr. T. Caruso, Sensors

LRC

Mr. J. Schrader, Communications Technology

Mr. S. Peterson, Instrumentation

Lincoln Laboratory (M.I.T.)

Mr. Phil Waldron, Staff, Satellite Communications

Mr. D. Maclellan

Mr. R. Berg

Aerospace Corporation

Mr. H. Meyers, Group II Engineering

Dr. F. Bond

During the critique of critical issues, the following subjects were given particular attention by non-study-team experts:

Subject	Overview Reference
RFI Studies	(5.1.2.2, 5.1.2.3.4)
Data Collection Techniques	(5.1.1.4)
Reflectivity	(5.1.2.3.2.8)
Multipath	(5.1.2.3.5)
Propagation Attenuation — Airborne to Space	(5.1.2.3)
Onboard Processing	(5.1.2.4.6)
Random Access — Multiple User	(5.1.2.4.1, 5.1.1.4)
Millimeter Wave System	(5.1.3.2, 5.1.1.1.1.3) (5.1.3.2)
Pattern Shaping-Beam Forming Antenna	(5.1.2.4.2)
Multibeam Lens — Phased Array, Narrow	(5.1.2.4.2)
UHF Large-Aperture Antenna	(5.1.2.4.2)
Laser Technology	(5.1.3.3)
Filters	(5.1.2.4.7)
High-Power Transmitters	(5.1.2.4.4, 5.1.1.2)
Hyperbolic Versus Spherical Position Location	(5.2.2)
Range-Range Rate Navigation	(5.2.1.1, 5.2.2)
Navigation and Traffic Control, Ground Segment	(5.2.1.1.5, 5.2.2.1.11) (5.2.2.2, 5.2.3.2)
Marine Geodetic Systems	(5.1.1.4)
TV Distribution	(5.1.1.2)
Auto Station Keeping — Long-Life Stabilization	(5.1.2.4.12)
Frequency Allocation	(5.1.3.1, 5.1.3.5)

2.6.1.5 Source Documents

Communications and Navigation Program Documentation, Preliminary Draft, NASA, Sept. 1969.

Useful Applications of Earth-Oriented Satellites, Report of the Central Review Committee, National Academy of Sciences, National Research Council, 1969.

Useful Applications of Earth-Oriented Satellites, Summaries of Panel Reports, National Academy of Sciences, National Research Council, 1969.

Useful Applications of Earth-Oriented Satellites, Volumes 7 through 11, National Research Council, 1969.

Radio-Frequency Interference Experiment Design for the Applications Technology Satellite, V. F. Henry (Goddard Space Flight Center) and J. J. Kelleher (NASA Headquarters), NASA Technical Notes, May 1969.

Navigation/Traffic Control Techniques Experiment Study, Final Report, Westinghouse Defense and Space Center, September 1966.

Multikilowatt Transmitter Study, Phase II Final Briefing, General Electric 27 May 1969.

Information Transfer Requirement Study, Briefing Slides, Contract No. NAS 2-5352.

Navigation/Traffic Control Satellite Mission Study, Volume I, Summary; Volume II, System Analysis; Volume III, System Concepts, TRW Systems Group, June 1969.

The Biomedical Communications Network, Technical Development Plan, National Library of Medicine, June 1968.

Man's Geophysical Environment-Its Study from Space, "Chapter 2 Proposed Environmental Measurements from Space,"ESSA Administration, U. S. Department of Commerce, March 1968.

"An Overview of Millimeter Wave Systems," Julian W. Dees, and Dr. James C. Wiltse, Martin Marietta Corporation, Microwave Journal, November 1969.

An Evaluation of Television Broadcast Satellite Systems, R. W. Hesselbacher, General Electric Company, AIAA Paper No. 68-1061, October 1968.

Satellites for Television Instruction, R. W. Hessenbacher, General Electric Company.

Feasibility Study of Man-Made Radio-Frequency Radiation Measurements from a 200-Mile Orbit, General Dynamics, 15 February 1968.

Methods of Predicting the Atmospheric Bending of Radio Rays, B.R. Bean, G. D. Thayer, and B. A. Cahoon, NBS Report 6056, U. S. Department of Commerce, 18 May 1959.

"Aircraft to Satellite SHF Communications," Harold E. Weber, AFSC, Wright-Patterson AFB, Microwave Journal, October 1969.

Space Broadcasting — How, When and Why, R. P. Haviland, General Electric Company.

2.6.2 Critical Issues for Research

As noted above, critical issues identified as a result of the analysis described in Subsection 2.6.1 are listed in Table 5 in Appendix B under the subdiscipline headings. The critical issues are numbered with multidecimal serial numbers corresponding to the numbering system of the organized overview.

2.7 ORGANIZED OVERVIEW ANALYSES OF EARTH OBSERVATIONS

A series of analyses have been performed to derive the objectives (with emphasis on those that imply experimentation in space) of the discipline of Earth Observations. At NASA direction, seven major subdisciplines within the scope of Earth Observations were separately analyzed. These subdisciplines are Earth Physics (including Geodesy); Agriculture, Forest, and Range Resources; Geography, Cartography, and Cultural Resources; Geology; Hydrology and Water Resources; Oceanography and Marine Resources; and Meteorology.

The analyses were characterized by the development of organized overviews (as described in Subsection 2.1) for each discipline, based upon broad objectives having NASA concurrence and reflecting some supporting objectives also furnished by NASA. Major subdiscipline areas for research were identified, reflecting the requirements of both the scientific community and user agencies. By d -fining successive subobjectives within each major subdiscipline area, critical issues (or research objectives) were identified, some of which may be accommodated by remote sensing from earth orbit.

The primary reference documentation for the definition of the broad NASA goals and objectives within the several disciplines of Earth Observations were the scientific goals and objectives furnished to the study team by the NASA Langley Research Center (Reference 2-6) and the Earth Surveys Program Documentation (Reference 2-7). In deriving the detailed subobjective portions of the organized overview charts, the study team was aided by the availability of reports from NASA, the National Academy of Sciences, other government agencies and committees, institutional organizations, and various industrial contractors (References 2-8 through 2-19). As the overviews for each of the disciplines took shape, conferences were held with non-study team authorities representing government agencies and the scientific community in the applicable fields. The persons with whom consultations were held are listed below. These meetings provided independent evaluations of the analyses and produced many suggestions for improvements in the organized overviews.

1. U. S. Department of Agriculture, Robert H. Miller, Agriculture and Forestry.
2. U. S. Geological Survey, A. C. Gerlach, Geography and Cartography.
3. U. S. Geological Survey, W. A. Fischer, Geology and Mineral Resources.
4. U. S. Geological Survey, C. J. Robinove, Hydrology and Water Resources.
5. U. S. Navy Spacecraft Oceanography Project, J. Sherman and H. Yotko, Oceanography.
6. Bureau of Commercial Fisheries, P. Maughan, Oceanography.
7. Smithsonian Astrophysical Observatory, P. Mohr, Earth Physics (Geodesy).
8. National Center for Atmospheric Research, W. W. Kellogg, Meteorology.
9. University of Wisconsin, V. E. Suomi, Meteorology.
10. Institute of Atmospheric Physics, University of Arizona, L. Battan, Meteorology

The organized overviews are presented as Charts 6-1 through 6-29 in Appendix A. These charts show all of the subdivisions of the objectives and subobjectives down to, but not including, the critical issues. The critical issues are collected in outline form in Table 6 of Appendix B.

2.7.1 Earth Physics

The organized overview of objectives in Earth Physics is presented in Charts 6-2, 6-3, and 6-4 in Appendix A.

Overall objectives in Earth Physics have shifted in the past decade from essentially descriptive measurements to the more basic objective of understanding the mechanisms that determine the state and changes of state of the earth. This shift has resulted from the orders-of-magnitude improvements in the accuracy of measuring the shape, gravitational field, and motions of the earth through the use of satellites. Detection of changes of state of the earth has become possible and has opened the area of the theory of Earth Physics to actual comparison with measured data. Hence, the NASA Williamstown Study (Reference 2-14) was able to identify a new level of objectives, that of testing global theories, whereas past emphasis has been limited to increased measurement accuracy in geodesy. The following questions (with procedures for obtaining solutions) are posed as goals:

1. What are the long-term dynamics of the solid earth? Identify the driving forces and response mechanisms that account for plate motions, earthquakes, variations in gravitational field, and tectonics.
2. What is the general circulation of the oceans? Account for the observed currents, temperature, and salinity; infer the necessary return flows; furnish inputs to numerical weather prediction. (See Oceanography.)
3. What is the earthquake mechanism? Improve understanding of how earthquakes occur, thus improving protection against tsunamis and earthquakes.
4. What is the nature of the global heat balance? Describe the relation between currents and heat transport; increase knowledge of air-sea interaction; detect changes in state of a long-term global nature.
5. What is the nature of the geomagnetic dynamo? Identify the energy source and mechanisms of interaction in the core, and hence account for the patterns of the internal magnetic field and the variation in the core-mantle coupling.
6. What is the rate and mechanism of energy dissipation in the oceans? Define the locations and mechanisms of energy dissipation, and thus explain such phenomena as damping of the Chandler wobble, the ocean tide pattern, and evolution of the earth-moon system.
7. What are the rotational dynamics of the earth? Explain the entire complex of excitational mechanisms, rheology, resonances, damping, etc., associated with the spectrum of variations in the rotation rate and wobbles of the rotation axis.

The above goals appear as Items 6.1.1.1 through 6.1.2.5 of the overview (Chart 6-2 in Appendix A) as they relate to state and change of the earth. Because some of these goals relate to measurements and theory that properly belong in another discipline, only the first three and the last are treated further in the overview for Earth Physics.

In the area of Solid Earth Dynamics (Item 6.1.1.1, Chart 6-2), the traditional subdivisions of geodesy apply: Measurement of Geometry (Item 6.1.1.1.1, Chart 6-3) and Measurement of Gravimetry (Item 6.1.1.1.2, Chart 6-3). A new emphasis appears in that the measurements now have achieved an accuracy that permits determination of variation with time.

The area of Ocean Circulation (Item 6.1.1.2, Chart 6-2) divides into Geopotential Field (Item 6.1.1.2.1, Chart 6-3), Mean Ocean Surface Height Above Geoid (Item 6.1.1.2.2, Chart 6-3), and Positions and Velocities for Navigation (Item 6.1.1.2.3, Chart 6-3). It should be noted (Item 6.1.1.2.1, Chart 6-3) that the problem is to measure the variations in the mean ocean surface with respect to the geoid, not with respect to the geocenter.

In the area of Earthquake Mechanism (Item 6.1.2.1, Chart 6-2), the advent of very long baseline interferometry (VLBI) and of laser tracking has opened whole new areas of interest.

In the area of Earth Rotational Dynamics (Item 6.1.2.5, Chart 6-2), the groupings reflect the definition of points in an inertial frame, polar motion, rotation, and inertial direction finding. Here again, VLBI and laser tracking have opened new areas of inquiry.

2.7.2 Agriculture, Forest, and Range Resources

Agriculture, forest, and range resources (Charts 6-5 through 6-8 in Appendix A) are used to feed, clothe, and house mankind. Agriculture is the growing of grain, fruit, and meat for food, and of fiber for clothing and artifacts. Forest resources produce wood products-lumber for buildings, pulp for paper, and hardwood for furniture. Range resources are the maintained ranges where cattle and sheep are raised and the wildlands where caribou, geese and other game animals live.

The broad objective of Agriculture, Forest, and Range Resources Management (Item 6.2, Chart 6-5) is to increase and improve the quantity and quality of food, clothing, and housing available for mankind by using man in space to develop related knowledge. This objective is a consensus of reports and papers published by the National Research Countil (References 2-8 and 2-9), the Committee on Science and Astronautics of the 90th Congress (Reference 2-10), the U. S. Department of Agriculture (Reference 2-19), NASA (References 2-2, 2-7, and 2-17), and of individual agronomists (References 2-20 through 2-22). Knowledge is needed on how much land is being used to produce food, fiber, and wood, and on how efficiently these lands are used. The fundamental importance of land use also is recognized by NASA. For example, the first user-oriented objective of the Earth Resources Technology Satellite (ERTS) system is a gross land use system (Reference 2-7). The agronomist also must acquire information on the current and future yield and vigor of crops on a state, national, and international level. This acquired knowledge will be used to improve the management of agriculture, forest, and range resources for the benefit of mankind.

Knowledge is acquired by determining the types of knowledge needed (Item 6.2.1), the sources of this knowledge (Item 6.2.2), and the uses of the knowledge (Item 6.2.3). These are the three specific applications shown on the second level of the agriculture overview analysis in Chart 6-5 in Appendix A.

The types of knowledge to be acquired are important because they define th. r data that should be gathered. This, in turn, indicates the sensors that are needed, the degree to which man participates in gathering data, and the type of space vehicle needed to accommodate man and his instruments. In Chart 6-5, knowledge is further divided into three fundamental categories: current crop inventory and yield, designated State (Item 6.2.1.1); future inventory and yield, designated Prediction (Item 6.2.1.2); and Production and Distribution (Item 6.2.1.3). Production and Distribution are included because some authorities believe the basic problem is not simply producing more food, but better distribution of the food that is produced.

State and Prediction are further subdivided in Chart 6-6 into the fundamental categories of Location and Inventory of the world's food, fiber, and wood products (Items 6.2.1.1.1 and 6.2.1.2.1), the Species and Vigor of crops (Items 6.2.1.1.2 and 6.2.1.2.2), and the condition of the Soils and Water environment (Items 6.2.1.1.3 and 6.2.1.2.3). Data in these three categories will give the agronomist a working knowledge of the current and future states of agriculture.

The fundamental activity in this resource area is the location and inventory of the world's supply of food, fiber, and wood for crop reports (Items 6.2.1.1.1 and 6.2.1.2.1, Chart 6-6). Crop reports are the principal tool used by the

Department of Agriculture. Thus, the use of manned satellites to expand and improve present methods is important.

Another important category in determining the present and future supply of food and fiber is the fertility, purity, and supply of Soils and Water (Items 6.2.1.1.3 and 6.2.1.2.3, Chart 6-6). Soil fertility consists not only of the plant food in the soil but also of its friability; its content of organic matter, beneficial insects, and micro-organisms; and the presence of trace elements. How well these properties can be determined from space is an important issue.

The second category from which the knowledge is acquired, Sources (Item 6.2.2, Chart 6-5), places heavy emphasis on man's role as an experimenter. His unique ability for reasoning, planning, observing, analyzing, adjusting, etc., will accelerate the development of improved beneficial space systems (References 2-11 and 2-12). It is in this category that the experimental team, consisting of the principal investigator on the ground and the experimental scientist in space, will be developed. Data Analysis (Item 6.2.2.2, Chart 6-5), including resource modeling, is as important as Data Collection (Item 6.2.2.1, Chart 6-5) and is included under sources of knowledge.

Not only the vehicle and its payload, but also the entire mission must be planned with the data needs of the user in mind. Mission-oriented experiments should be performed to determine the acceptable limits of illumination, weather, atmospheric clarity, slant range, etc. These Mission Parameters (Item 6.2.2.3) are included under sources of knowledge in Chart 6-5.

The third category listed under acquisition of knowledge on Chart 6-5 is current and future Uses (Item 6.2.3) of the knowledge. The ultimate use either is Economic (Item 6.2.3.1, Chart 6-8) and can be evaluated in dollars, or it is Social and Cultural (Item 6.2.3.2, Chart 6-8) and is evaluated in terms of the general welfare. The uses of the acquired knowledge are shown on Chart 6-8 as International (Items 6.2.3.1.1 and 6.2.3.2.1) as well as National (Items 6.2.3.1.2 and 6.2.3.2.2) and Local (Items 6.2.3.1.3 and 6.2.3.2.3). A satellite collects data across national boundaries, agriculture is an international business, and the subdivision of Uses (6.2.3, Chart 6-5) into the three categories reflects this. Forest and range resources include recreational benefits to mankind as well as food. The conservation of natural recreational resources and the detection of pollution are particularly important and are included as critical issues under social and cultural uses.

Usually, the preferred format for collected data is a map. In Reference 2-20, however, the author points out that the question of the superiority of maps versus statistics for certain aspects of forestry is still an unresolved issue. It is often claimed that an advantage of manned space research in this area is that the in-orbit experimenter can improve reliability and data quality through the performance of onboard calibration, repair, etc. The degree to which this is true is the subject of several critical issues under Data Collection (Item 6.2.2.1, Chart 6-5). Similarly, critical issues under Data Analysis (Item 6.2.2.2, Chart 6-5) are addressed to the question of whether man can perform valuable data analyses and reduction in space.

During a conference with Department of Agriculture personnel, it was emphasized to the study team that an issue of critical importance was a replication of experiments on crop inventory and yield performed at Purdue Farms and other ground truth sites. Consequently, the theme of experiment replications runs throughout the critical issues (Table 6 in Appendix B) under Sources (Item 6.2.2, Chart 6-5) An example is the critical issue of how frequently samples should be taken and how large the sampling area should be (Item 6.2.2.1.3, Table 6).

Other critical issues under Data Analysis (Item 6.2.2.2, Chart 6-5) that are related to experiment replication are modeling (Item 6.2.2.2.1, Table 6) and the several others related to the data needed as inputs to the resource models that are being developed by the Department of Agriculture. Experiment replication appears under Mission Parameters (Item 6.2.2.3, Chart 6-5) in the issue, "What coordination with ground truth sites and aircraft flights is needed?" (Item 6.2.2.3.6, Table 6).

The critical issues under Sources (Item 6.2.2) also stress the need pointed out in References 2-17 and 2-23 for man in space as part of the experimental team. Examples of this are the issues, "How effectively can an experiment scientist recognize and track a resource from space?" (Item 6.2.2.1.5, Table 6) and "How much data reduction should be done in space?" (Item 6.2.2.2.6, Table 6).

2.7.3 Geography, Cartography, and Cultural Resources

The organized overview analysis of the objectives of future geographic and cartographic missions from space was based in part on the April 1966 conference report on the use of orbiting spacecraft in geographic research.* The analysis was enriched by inputs from non-study-team authorities, notably Dr. L. Bowden of the University of California at Riverside, Dr. J. Bailey of ONR, and Dr. A. C. Gerlach of USGS, to reflect updated thinking resulting from the analysis of Gemini and Apollo photography.

The broad objectives in developing the sciences of geography and cartography from space are:

1. To acquire knowledge of the spatial patterns of natural and cultural phenomena and the interactions with human activities.
2. To gather geographic data important to a better understanding of the earth's environment as an aid to planning wise use of the planet.
3. To provide a base for interactive studies of resource utilization, settlement and population dynamics, urban data, transportation, linkages, and historical geography.

Man's conquest of the space environment has provided a vantage point from which significant quantities of usable synoptic data can be recorded, reduced, and disseminated to users in a meaningful time frame.

The geographic and cartographic technologies represent a scientific community deeply involved with the analyses of dynamic data that are worldwide in scope

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*Use of Orbiting Spacecraft in Geographic Research, National Academy of Sciences Report of Conference at NASA Manned Spacecraft Center, Houston, Texas, April 1966.

and implications. Geographic studies fundamentally deal with the distribution patterns and spatial relations of physical and cultural characteristics of the earth. Significantly, these studies are primarily concerned with the continuing changes that result from man-environment interactions.

The intricate interrelations of man-environment interactions brings geography into very close, and in many instances overlapping, relations with other disciplines. This fact is attested by the critical issues (the end products of the organized overview analysis), which in many instances are of primary concern to other major disciplines, yet are applicable to geography and cartography. The critical issues also indicate that many of the research objectives do not readily meet the requirements for solution by space technology applications, but rather require ground-based research involving long-term data accumulation or the use of instrumentation that is not yet available.

The application of space technology by the geographic and cartographic community will, however, for the first time provide sufficient data within a usable time frame to accomplish many of the tasks heretofore considered impossible or impractical. It remains, then, to determine exactly what can best be accomplished from space to advance the science of Geography and Cartography for the ultimate benefit of man. The need for such a determination provides the basic rationale for the development of an all-inclusive overview.

The organized overview format used in this study provides a logical and increasingly specific progression to the critical issues, which represent the specific, significant research objectives of the discipline. The organized overview of geography and cartography, which presents the interrelationships between the uses of geographic and cartographic information, special knowledge requirements, and the effects of man's interactions with his environment, is presented in Charts 6-9 through 6-14 in Appendix A.

The Geography and Cartography organized overview is numbered from the general objective, a two-digit number, to the specific categories (five- and six-digit numbers). Numbers are applied to the categories to give flow continuity to the sequence of charts forming the total overview.

Particular importance is attributed to the three-digit, or specific application, level of the overview. It is at this level that the most significant development of space applications in the geographic and cartographic community becomes evident. Uses of space-derived geographic and cartographic data are of paramount importance, for it is the uses to which these data may be most effectively applied that provide the means of achieving the stated objectives. As the uses for geographic and cartographic data are prescribed, the synthesizing, assimilation, and finally the detailed analysis of these data may be accomplished. A specific body of knowledge will emerge after the accumulated data have been applied to the prescribed uses. The integration of knowledge gained from the application of these data will provide man with a new and unique opportunity to use time-variant data needed for the understanding of his complex environment.

At the four-digit level of the organized overview, the following questions were posed as goals:

1. Economic (6.3.1.1)-What are the economic contributions of geographic and cartographic studies to man's environment and the social structure?
2. Social and Cultural (6.3.1.2)-What are the social and cultural rewards of geographic and cartographic applications to society?
3. National and International (6.3.1.3)-What are the national and international applications of geographic and cartographic techniques?
4. Evolution (6.3.2.1)-What were the origin and evolution of the earth's land surfaces and man's adaptation to these environments?
5. Status (6.3.2.2)-What is the present state of the land surfaces and man's utilization of them?
6. Change (6.3.2.3)-What knowledge and understanding of man's environment and social structure are required for attempting modification and control of the environment?
7. Climate (6.3.3.1)-How do the earth's surface features and their location affect climates and migration of population?
8. Resources (6.3.3.2)-How do the interrelations of the earth's surface features relate to its resources and man's cultural development?
9. Ecosystem (6.3.3.3)-What are the effects upon the bio-atmosphere induced by man's role in changing the environment?

The questions addressed at this level of the overview demonstrate the synergism that exists between geography from space and other scientific and social disciplines. At the critical issue level of the overview (six- and seven-digit entries listed in Table 6 in Appendix B), the driving functions for specific mapping requirements, observation techniques, and research requirements are identified.

2.7.4 Geology

The tremendously enlarged United States and worldwide demands for natural resources have introduced a note of urgency into the development of methods for finding and inventorying these resources. It has been estimated that during the past 30 years, the United States alone has used more minerals and fuels than the entire world used in all previous history, and that the United States will double its present rate of consumption of most minerals within 15 to 25 years. The problem is compounded by the growth in population and the concurrent rise in per capita consumption of raw materials and energy. The application of spaceborne remote sensors promises to accelerate man's ability to discover and evaluate natural resources and to develop new knowledge of the overall characteristics and distribution of these resources.

From the foregoing information, a need is recognizable for determining specifically what research objectives are important in acquiring meaningful data from space about geological resources. To facilitate determining these research objectives, a comprehensive, research-oriented, organized overview of geology has been developed and is displayed in Charts 6-15 through 6-19 in Appendix A. These charts start from the basic objective in Geology (Item 6.4 Chart 6-15) and divide into narrow-cut objectives as lower levels are reached. This process finally leads to the research-sized objectives of space applications to geology, i.e., the critical issues in geology.

The logical structure of the analysis is well suited to providing a progressively more intimate overview of geology and its fundamental relations with society. The basic Geology objective (Item 6.4, Chart 6-15) leads to the specific application areas where questions arise concerning the use to which geologic studies and data can be applied.

Uses (Item 6.4.1), as a major subdiscipline area, leads to the consideration of Economic (Item 6.4.1.1) and Social and Cultural (Item 6.4.1.2) application areas shown on Chart 6-15. The economic applications are subdivided (Chart 6-16) into five specific categories that yield 10 critical issues shown in Table 6 of Appendix B. Social and cultural uses were derived under two specific categories (Chart 6-16), providing 8 critical issues or research objectives (Table 6).

Many remote sensor observations and measurements are also applicable to problems in other disciplines concerned with natural resources. This overlapping relationship is readily seen in the study of geology, i.e., in Knowledge (Item 6.4.2). Three application areas evolved as subobjectives to gaining knowledge-Evolution (Item 6.4.2.1), State (Item 6.4.2.2), and Change (Item 6.4.2.3)-are also shown on Chart 6-15).

The area of Evolution was further subdivided into four specific categories (Chart 6-17) yielding 12 critical issues (Table 6). All of these critical issues are considered to be of primary importance to disciplines other than geology and yet are of fundamental importance to the geologist.

The area of State was subdivided into four specific categories (Chart 6-17) providing 16 critical issues. The area of Change was further subdivided into six categories at two levels (Chart 6-18), yielding a total of 35 critical issues.

The third major subdiscipline area, Effects (Item 6.4.3, Chart 6-15), was subdivided into Weather and Climate (Item 6.4.3.1), Global Dynamics (Item 6.4.3.2), and Biota (Item 6.4.3.3). Nine specific categories (Charts 6-18 and 6-19) identifying 39 critical issues evolved from these areas. The basic geologic objectives also lead to the areas of Knowledge and Effects. These general categories seem naturally related to the great, unresolved critical issues of esoteric research elements in geology. As a class, those critical issues are seen to be heavily influenced by the general subject of massive, long-range crustal instability. Examination of these critical issues brings to mind some of the fundamental problems of geology. The major processes occur on a very large scale (perhaps even a continental scale) over eons of time and at great, inaccessible depths. The time and inaccessbility problems associated with the massive nature of the phenomena can very well be best approached from a new perspective and at a scale of observation attainable only from an orbital vantage point.

The organized overview, as indicated, relates the specific subjects that should be pursued to enhance man's use of the earth to achieve the vital research objectives of geology.

The discipline of geology is so intimately related to a number of other disciplines that a clean, simple interface does not exist. Geology and agriculture interface with regard to soils. The nature of the soil is strongly related to many geologic features, such as parent rock type and methods of weathering and deposition. Geodesy and geology touch in the fields of isostasy and possible continental movement. Geology and astronomy are related through the subject of cosmogony. The organized overview reflects these relationships to the extent that if a critical issue is to be treated by an overlapping discipline, an appropriate symbol is appended in the table of critical issues (Table 6)

The organized overview outlined above paves the way for the generation of an information package for each critical issue or logical grouping of critical issues. Although the organized overview is suited to this purpose, there are problems in developing highly detailed experimental approaches to the basic questions in geology. The entire geologic profession has not yet been able to accomplish this. It would seem that the practical approach is to take the critical issues from the Users area of the organized overview and group them into research areas. The information requirements of these areas, taken in the aggregate, encompass the range of geologic research issues given under Knowledge and Effects. This problem can be summarized as a lack of knowledge of how to relate remote sensing to geologic applications. If it is acknowledged, however, that an evolutionary process will be required before the benefits from geologic developments can be realized; and if certain troublesome problems (such as that of spatial resolution) can be rationalized by showing how analogous problems are solved (in photointerpretation, for example), it will be possible to prepare the information packages for the critical issues under Uses. There is good reason to do this rather than abandon geology, because a new look at the problems with orbital-perspective scale may well provide the catalyst required for great gains in geologic knowledge, and because such gains might have a very beneficial effect on the other disciplines.

With reference to the subjects found under the Uses portion of the organized overview, the broad goal of geology is to acquire knowledge so that man can better understand the theoretical and applied aspects of the earth for maximum use and management of its processes and resources. Following the tenor of thought above, the five major research areas selected relate to:

1. Surficial Geologic Mapping-Mapping is a probable first step in realizing the geologic potential of applying remote sensing technology. This survey will provide basic information, relating to the location of arable lands, construction materials, some aspects of engineering site selection, and trafficability. Detailed information will be obtained with regard to chemical composition, mineral content, grain size distribution, crystal size distribution, jointing factors, specific gravity, drainage pattern descriptors, land form definition, permeability, microstructure descriptors, Atterberg limits, void ratio, compaction factors, arrangement of strata, depth and areal extent of surface material, and bearing strength.

2. Development of Information on Deep-Seated Geologic Formations — A primary goal of this effort is to locate potential mineral and fossil fuel deposits. Sensing of actual deep-seated phenomena from space is not considered practical. The construction of a geologic synthesis based on surface data is quite possible, however, and is basically the approach that geology has always followed. To this basic approach is added information developed from magnetic and gravitational anomaly mapping, and possibly some radio-frequency sensing to obtain as much penetration as possible. From the synthesized geologic model, the presence and location of the mineral or petroleum deposits are deduced. The data developed will relate to the identity of the primary deposit, the identity of secondary deposits, estimates of concentration and size of all deposits, forms of deposits (impurities, combinations), geologic and geomorphologic descriptions of host formations, and spatial configurations of host formations. Materials sought will include fossil fuels (coal, oil, natural gas), abrasives, refractories and insulators, sulphur and sulphates, fertilizers, clays, and metallic

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ores (iron, copper, lead, etc.). Minerals will be sought in magmatic provinces, hydrothermal deposits (in metamorphic provinces, veins, and hot-spring areas), sedimentary beds, stream beds,*evaporation deposits, ground water deposits,* and weathering deposits.

Use of the Earth's Crust to Store Commodities and to Condition Waste— This area will use the comprehensive knowledge of the earth's crust developed in the two subjects discussed in Items 1 and 2 above. This basic information will be turned to a new direction. The water resource management problem involves the status of the water table, which is in turn influenced strongly by geological factors. As water becomes more critical, as it is expected to do, it may be desirable to seek means of practical geological modifications that will tend to control the activities of ground water. Geology is also a critical factor in surface reservoir development. In addition to destroying the capacity of a dam to impound water, underground seepage can precipitate many undesirable side effects, such as the development of boils or quick conditions which, if not controlled in a timely fashion, can cause land flooding.

The use of an artificial means to store water is a very complex subject, the Aswan dam being a case in point. Some experts now think that the amount of land that will be added to agricultural production by the dam will soon be lost in the Nile delta because of erosion. The erosive action always existed, of course, but was offset by the sedimentation action of the river. This sedimentation is now drastically reduced by new conditions created by the dam.

The problem of waste conditioning is associated with the broader pollution problem. The focus of the pollution facet will be on the reduction of synthetic products. The solution will probably be an expeditious use of natural geologic formations, supplemented by special treatment. Radioactive materials pose a special threat. Only small amounts of such materials are expected, but the undesirable features are of extremely long range, and if not handled with great wisdom now, they could well pose a serious threat to mankind far in the future.

4. Geologic Disaster Avoidance and Associated Controlling-Structure Site Selection — This area is quite broad and involves quite different current knowledge levels, depending on the nature of the threat. Some factors relating to dam site selection were touched upon above. Again, the information developed in the research areas already listed is highly pertinent to this area. However, this research area emphasizes a new dimension of the overall geologic subject as delineated thus far. The new factor is the knowledge level in basic geology regarding the causes of some disastrous phenomena, such as volcanos and earthquakes. Tectonic and volcanic activity seem to be closely

*Interface with surficial mapping.

associated and would appear to be related to the general subject of crustal instability. The basic causes of crustal instability are a subject of controversy, however. The long-range effects of erosion could be a prime factor. On the other hand, the slow release of energy from deep in the earth may be the primary cause. The lack of factual knowledge, and in some cases the lack of working hypotheses, hampers the long-range prediction of volcanic eruptions and earthquakes. With regard to these kinds of subjects, there is a need for a substantial increase in basic geologic knowledge before the potential of the subject can begin to be realized. Other areas, such as potential landslide detection, can be reduced to a relatively straightforward problem on the basis of today's knowledge. The kinds of phenomena to be considered include volcanos, earthquakes, erosion, transportation, deposition, and subsidence threats.

5. Utilization of Geothermal Energy Sources-This research area can make excellent use of knowledge gained from the first three areas mentioned above. Sources of energy will be located and classified. Two natural factors associated with the use of such energy should be mentioned here. The first is the source of the energy, which will usually be deep-seated magma or rock resulting from the cooling of ancient magma. The second factor is the easiest method of extracting the energy available. In this connection, the use of natural ground water is highly attractive (hydrothermal energy). In rare cases, this can be done where the heated water rises to the surface at hot springs. This energy source seems to be worldwide. Since the specific geological conditions giving rise to hot springs are comparatively rare, however, new means will probably be required to artificially create conditions where ground water can be used, or other types of engineering developments will be needed. Some authorities feel that such an energy source may be needed by the end of the present century.

2.7.5. Hydrology and Water Resources

Hydrology is the environmental science directly concerned with the distribution and quality of water above, on, and below the surface of the earth. This science is concerned with the entire hydrologic cycle, the phases of which are evaporation (from the ocean, lakes, streams and the soil), transpiration (from vegetation), condensation of water vapor in the atmosphere, precipitation, and runoff of surface water and subsurface water. Applied hydrology is concerned with the practical use of terrestrial water for industrial, agricultural, and domestic purposes. This science interfaces with many others-meteorology, agriculture and forestry, geology, geography, and oceanography.

Large gaps exist in the theory of hydrology, and a physical-mathematical model of the general hydrologic cycle is lacking. Only limited data are available for defining the discharges of major rivers, and the world's total water budget is not known with confidence. Vast sums of money are spent for the development of water resources, but planning in recent years has been conducted only on a regional basis. Within the United States, the regional use of water has at times been restricted because of conditions caused by drought. The present level of engineering knowledge in this science is grossly inadequate to meet future national and international needs (Reference 2-24). The problem of contamination of ocean water and beaches by offshore drilling operations and tankers, as well as by the pollution of rivers and estuaries by industrial chemicals, is now recognized as a major problem.

The recognition that the world water balance is rapidly becoming an international problem has led to the establishment of the International Hydrological Decade within UNESCO, with nearly 100 countries participating. The Hydrology Technical Panel, which participated in the Woods Hole Summer Study, has recommended a program comprising a worldwide water information system to provide engineering management and scientific data, and the initiation of education and training programs in this environmental science.

Earth-oriented satellites using both remote sensing and data relay capabilities can provide data that cannot be obtained economically by other means on a global scale. Major current needs are the ability to forecast rainfall, streamflow, and snow-water content and rate of melt, and the ability to transmit this information rapidly to using agencies. The limited applications of space technology to date have been of extreme benefit to hydrologic problems. Data obtained from ESSA meteorological satellites have been used to forecast snow melting and flooding conditions in the midwestern states, and resulting corrective action has prevented great losses of life and property. The benefits to be derived from forecasting, and eventually controlling, the sources of flood, drought, and pollution are enormous.

Unmanned satellites can provide an economical means of remote sensing with imaging and microwave sensors, and of collecting and relaying data from ground-based sensors of hydrologic data. Manned satellites, with a larger payload capability, offer the advantage of obtaining high-resolution photographic data of metric quality in clear weather and high-resolution radar imagery under all weather conditions, and the flexibility of incorporating improved remote sensors on a quick-reaction basis without the prohibitive schedules entailed in development of automated equipment.

The broad goal of hydrology is to attain sufficient knowledge of the environment to enable understanding, prediction, and timely management of the water resources of the Earth (Item 6.5, Chart 6-20). The primary needs of this environmental science have been defined at the Woods Hole Summer Study as: (1) those required for better utilization of water resources and (2) those required for a better understanding of the hydrologic cycle. These requirements have been used as the basis for the structure of the organized overview that has been developed for the definition of research objectives (illustrated in Charts 6-20 through 6-23 of Appendix A).

Two major objectives are thus defined for further analyses: better Utilization (Item 6.5.1) of water resources, and better Scientific Understanding (Item 6.5.2) of the hydrologic cycle to enable prediction of water resources.

From these major objectives, four subobjectives are derived as shown on Chart 6-20: (1) the Knowledge (Item 6.5.1.1) requirements in the form of hydrologic data required for better Utilization (Item 6.5.1) of water resources; (2) determination of the dynamic Effects (Item 6.5.1.2) of the earth's environment upon Utilization (Item 6.5.1) of water resources; (3) Scientific Knowledge (Item 6.5.2.1) requirements for better prediction of water resources; and Understanding of Effects (Item 6.5.2.2) of changes in the environment of the earth upon the hydrologic cycle.

Application areas related to Knowledge (Item 6.5.1.1) and Utilization of water resources (Chart 6-21) are those of Water Management and Flood Control (Item 6.5.1.1.1), Inventory of Surface and Subsurface Water (Item 6.5.1.1.2), and knowledge of major drainage basin Topography (Item 6.5.1.1.3) characteristics. Dynamic Effects (Item 6.5.1.2) of the environment that affect utilization of water resources (Chart 6-21) are changes in Land Use (Item 6.5.1.2.1), Water Circulation (Item 6.5.1.2.2) in large bodies of water, and chemical and organic Water Pollution (Item 6.5.1.2.3).

Under Scientific Knowledge (Item 6.5.2.1) requirements for better prediction of water resources (Chart 6-22), those pertaining to the total Water Budget (Item 6.5.2.1.1) of the earth are knowledge of the precipitable Water Vapor (Item 6.5.2.1.1.1) in the atmosphere, the extent of Precipitation (Item 6.5.2.1.1.2), Evapotranspiration (Item 6.5.2.1.1.3) losses in semiarid regions, and determination of the amount of water held in the solid state as Snow and Ice (Item 6.5.2.1.1.4), in the form of Soil Moisture (Item 6.5.2.1.1.5), and in Surface and Subsurface Water (Item 6.5.2.1.1.6) reservoirs.

Knowledge of the total Energy Budget (Item 6.5.2.1.2) of the earth is also a requirement of the science of meteorology, encompassing knowledge of Solar Radiation (Item 6.5.2.1.2.1), Thermal Radiation (Item 6.5.2.1.2.2) emitted from the earth, heat transfer through the Atmosphere-Surface Boundary Layer (Item 6.5.2.1.2.3), the effects of Atmospheric Pollution (Item 6.5.2.1.2.4) (primarily carbon dioxide and particulate matter), and the effects of changing Land Use (Item 6.5.2.1.2.5) upon the energy balance.

Understanding of Effects (Item 6.5.2.2) of changes in the environment upon the hydrologic cycle (Chart 6-23) is also required. Primarily, this involves the effects of cultural changes in Geography (Item 6.5.2.2.1), Atmospheric Pollution (Item 6.5.2.2.2), and Weather Modification (Item 6.5.2.2.3), i.e., cloud and hurricane seeding experiments.

Within each of these major application areas, specific research objectives requiring understanding, information, techniques, or instrumentation to satisfy the needs of the area have been identified. These special research objectives, or critical issues, are listed in Table 6 in Appendix B and correspond to the major application areas in the organized overview of Charts 6-20 through 6-23 in Appendix A.

2.7.6 Oceanography and Marine Resources

To determine the research potential and experiment requirements for a manned space platform applied to oceanographic and marine resources, a research-oriented overview of the discipline was developed. This approach encompasses the organization of level-of-research objectives and their applicable sub-objectives. This form of organized overview analysis, increasing in detail with each level of subobjectives, eventually reaches specific research-sized issues that are critical to the achievement of the overall objectives. These critical issues represent the point where research is necessary to satisfy the objectives. (In this development, areas that did not appear to have potential for remote sensing were not considered in detail.)

The starting point for the current study in oceanography and marine resources is the analysis developed on Contract NAS8-21064 and published as McDonnell Douglas Report DAC-58121, Oceanography and Meteorology: A Systems Analysis to Identify Orbital Research Requirements (Reference 2-4). This study reviewed the literature and reports available up to early 1968 to develop a preliminary overview. The analysis was also reviewed by outside consultants. Each discipline was considered from the standpoint of three broad application categories: uses, knowledge, and effects. The same procedure has been followed in principle for Oceanography and Marine Resources (Item 6.6) in the current study (Charts 6-24 through 6-26). It was observed in this study that when the critical issues across the three major branches (uses, knowledge, and effects) were examined for commonality, the same spatial, spectral, and temporal oceanic and atmospheric parameters were involved in both the scientific and applications-oriented research areas. Because of this pattern of commonality it was only necessary to develop the knowledge branch to meet the NASA program objectives. Lacking similar study results in the subdisciplines of earth physics, agriculture/forestry, geography/cartography, geology, and hydrology, commonality assumptions could not be justified. Hence, the fuller development was necessary in these subdisciplines. Knowledge has been further subdivided into State (Item 6.6.1.1) and Change (Item 6.6.1.2), both in Chart 6-24. For the current study, the previous analysis has been updated and modified to reflect the present state of the art as well as new ideas and understanding. Specific inputs are discussed at the end of this section.

The basic objectives in Oceanography and Marine Resources (Item 6.6, Chart 6-24) are to increase utilization of the oceans for transportation, recreation, and food and resource production, and to understand the effects of the oceans on weather and climate. These objectives raise the question concerning Knowledge (Item 6.6.1): How can man's understanding of the physical, chemical, biological, and geological processes of the oceans be increased? Answers to this question can be divided into three basic application areas: evolution, state, and change. Since objectives concerned with the origin and evolution of oceans do not appear to lend themselves directly to remote sensing from space platforms, this subject area was not considered further. The basic questions in the other two areas are: How can the State (Item 6.6.1.1) of the ocean be described more effectively and accurately? What knowledge of the Changes (Item 6.6.1.2) that occur in the ocean is required for the prediction, modification, and control of the ocean's future states?

In the State application area, five specific categories are identified (Chart 6-25): Geophysical (Item 6.6.1.1.1), Physical (Item 6.6.1.1.2), Chemical (Item 6.6.1.1.3), Geological (Item 6.6.1.1.4), and Biological (Item 6.6.1.1.5). The questions in these categories have led to 22 critical issues, which are detailed in Table 6 of Appendix B.

In the Change application area, three specific categories are identified (Chart 6-26): Transformations (Item 6.6.1.2.1), Prediction (Item 6.6.1.2.2), and Modification (Item 6.6.1.2.3). Transformations (i.e., from one state to another) imply the possible involvement of energy, which may be converted from one form to another (e.g., heat energy to kinetic energy). The prediction category includes utilization of the ocean, since prediction of the future states will facilitate future utilization. Modification includes an understanding of changes of the state of the ocean. It also implies possible future control of ocean states.

In answering the question on Transformations (Item 6.6.1.2.1) of Chart 6-26 (How can the knowledge of the principles of theories of the transformations of state be improved?), five subcategories are identified: Momentum (Item 6.6.1.2.1.1), Energy (Item 6.6.1.2.1.2), Mass (Item 6.6.1.2.1.3), Biota (Item 6.6.1.2.1.4), and Sedimentation (Item 6.6.1.2.1.5), which lead to 25 critical issues in Table 6 of Appendix B.

In the case of Prediction (Item 6.6.1.2.2) of Chart 6-26 (How can prediction and utilization of the future states of the ocean be improved?), three subcategories are identified: Data (Item 6.6.1.2.2.1), Models (Item 6.6.1.2.2.2), and Technology (Item 6.6.1.2.2.3). The data category includes improvements both in the applicability of measurements and in data handling. The Models category is concerned with the improvement or development of descriptive and mathematical models to predict, utilize, modify, or control the ocean. Technology deals with improvements in platforms, instruments, communication facilities, and computation and display facilities. These three subcategories contain 30 critical issues, which are listed in Table 6 of Appendix B.

The Modification category (Item 6.6.1.2.3) of Chart 6-26 asks the question How can modification of the oceans be better understood and controlled? To answer this question, three subcategories are utilized: Air/Sea Boundary (Item 6.6.1.2.3.1), Solid Boundary (Item 6.6.1.2.3.2), and Internal Boundaries (Item 6.6.1.2.3.3). The air-sea boundary is concerned primarily with modification of the energy flux or partition at the sea surface. The Solid Boundary considers the changes in the shoreline and ocean bottom. The Internal Boundaries cover the effects that modifying the internal chemical, physical, or biological character of the ocean have on ocean processes. These subcategories have led to seven critical issues listed in Table 6 of Appendix B.

As mentioned earlier, the analysis from Reference 2-4 was used as a basis for the present work but was modified somewhat by considering only the State and Change application areas under Knowledge. The other major revisions were in the subcategories under Prediction, as are many of the critical issues under all categories. Some critical issues were unchanged, some were reworded, and a large number of new issues were formulated. Many of these revisions and additions were the results of discussions and comments resulting from Reference 2-4. Some were formulated from information presented at conferences or seminars sponsored by the interagency Spacecraft Oceanography Committee (SPOC). Many were the result of reviewing reports and articles available since the earlier study was completed. Some of these sources are the following:

1. Oceanography and Meteorology, a Systems Analysis to Identify Orbital Research Requirements - Addendum to Contract NAS8-21064 Douglas Missiles and Space Systems Division, McDonnell Douglas Astronautics Corporation, April 1968.

2. Useful Applications of Earth-Oriented Satellites, Woods Hole Summer Study, NAS/NRC, 1969.

3. Man's Geophysical Environment: Its Study from Space, U. S. Dept. of Commerce, ESSA, March 1968.

4. K. R. Stehling, "Remote Sensing of the Oceans," Astronautics and Aeronautics, May 1969, pp. 62-68.

5. Paul E. LaViolette, "Oceanography from Space - NOW, "Oceanology International, July August 1969, pp. 28-32.

6. C. A. Jacobs, J. P. Pandolfo, and E. J. Aubert, Characteristics of National Data Buoy Systems: Their Impact on Data Use and Measurement of Natural Phenomena, TRC Report 7493-334, Contract DOT-CG-82504-A, December 1968.

7. L. H. Clem and G. M. Northrop, Applicability of National Data Buoy Systems to Refined National Requirements for Marine Meteorological and Oceanographic Data, Vol. 1, TRC Report 7493-332a Contract DOT-CG-82504-A.

8. Abstracts of Reports presented at the Earth Resources Program - NASA Aircraft Project Second Annual Program Review, 1 to 18 September, 1969; NASA Manned Spacecraft Center, Houston, Texas, Proceedings, Sixth Space Congress, Volumes I and II, Cocoa Beach, Florida, 17, 18, and 19 March 1969.

9. Summaries, Sixth Symposium on Remote Sensing of Environment, 13 October 1969, Ann Arbor, Michigan.

10. Earth Resources Aircraft Program Status Review, Volume III, NASA Manned Spacecraft Center, Houston, Texas, 16 to 18 September 1968.

11. Our Nation and the Sea: A Plan for National Action, Report of the Commission on Marine Science, Engineering, and Resources , January 1969.

12. Panel Reports of the Commission on Marine Science, Engineering, and Resources, 1969:

Volume 1, Science and Environment
Volume 2, Industry and Technology
Volume 3, Marine Resources and Legal-Political Arrangements for their Development

13. Marine Science Affairs, Third Report of the President to the Congress on Marine Resources and Engineering Development, January 1969.

14. N. G. Jerlov, Optical Oceanography. Elsevier Publishing Company, New York, 1968.

2.7.7 Meteorology

The rationale for the overview analysis and for the derivation of critical issues in the meteorology discipline utilized the organization and analytical framework that evolved from earlier efforts, such as the Orbital Astronomy Support Facility (OASF) Study (Reference 2-3), and the Oceanography and Meteorology (O & M) Study (Reference 2-4). One important difference, however, is worthy of note. The O & M study analysis examined the universal goals in meteorology from the standpoint of the economic, social, cultural, and political uses of the atmosphere, as well as the effects that meteorological phenomena might have on man. The present overview developed for Meteorology (Charts 6-27 through 6-29 of Appendix A) is also responsive to the scientific and technological goals and objectives of NASA.

Specific scientific and technological objectives in the present overview reflect plans outlined by the NASA Earth Surveys Planning Panel (References 2-25 and 2-26). However, statements of basic objectives in meteorology appear to be consistently the same, regardless of the source. They are the description and understanding of the state and processes of change of the atmosphere, the accurate prediction of these changes, and the modification and control of atmospheric phenomena (Item 6.7, Chart 6-27).

Starting from this general statement of objectives, meteorology asks questions that relate to the scientific goals of the pursuit of Knowledge (Item 6.7.2), the Uses (Item 6.7.1) to which that knowledge could be placed, and the Effects (Item 6.7.3) that atmospheric phenomena might have on man.

In pursuing a research-oriented approach to the analysis and correlation of objectives, it was decided that the analysis of the discipline of meteorology would emphasize the scientific goals of the pursuit of knowledge. Thus, the Uses and Effects branches of the overview, being more application-oriented, were not pursued further.

The critical issues related to the first branch under Knowledge-Evolution (Item 6.7.2.1)-are developed on Chart 6-28 and listed in Table 6 of Appendix B. These critical issues are largely based on an analysis of the critical issues developed in Reference 2-4.

The rationale in examining the State (Item 6.7.2.2) branch under Knowledge was to define it as an instantaneous time slice of the atmospheric and boundary conditions. The three major branches under State indicate the research requirements in this area. These branches (Chart 6-28) are the Chemical (Item 6.7.2.2.1), the Physical (Item 6.7.2.2.2), and the Circulation (Item 6.7.2.2.3) states of the atmosphere.

The atmosphere of the earth is a single unit and is often and advantageously treated as such. But it is also conventional, for some purposes, to subdivide it, for example, into a number of spheres. Such subdivisions, and the subdivisions (branches) used in the present analysis, are to a certain extent arbitrary and do not necessarily indicate the presence of independent domains that represent separate problems and properties. The overlapping of the Chemical, Physical, and Circulation states of the atmosphere was considered in the analysis and in the identification of critical issues, and it is believed that the separate consideration of these states does not interfere with defining all of the critical issues. Examination of the Chemical (Item 6.7.2.2.1) state, for example, develops questions pertaining to what chemical constituents are present in the atmosphere, what their three-dimensional (temporal, areal, and vertical) distributions are, and what factors affect these distributions.

The Physical (Item 6.7.2.2.2) state of the atmosphere considers the optical, acoustical, electrical, and magnetic properties of the atmosphere. It also considers such air-transportable materials as sand, silt, clay, and dust. An example of the potential for overlapping occurs here. The physical state could have been defined to encompass thermodynamic properties, chemical composition, radiation characteristics, and the phenomena of clouds and precipitation. As generally accepted, it does not include motions of the atmosphere and the forces responsible for these motions, which are treated under circulation. In addition, atmospheric thermodynamics, which lies near the borderline of physical state and circulation state, was included in circulation. Thus, the Circulation (Item 6.7.2.2.3) branch of State, which is concerned with atmospheric motions and dynamics, was defined to include the mass, momentum, radiation, and temperature fields, as well as atmospheric composition and structure.

The third major branch under Knowledge is Change (Item 6.7.2.3), Chart 6-29, and derives from changes in the state of the atmosphere and its circulation. Knowledge and understanding of these phenomena constitute the prerequisites to prediction of the future state of the atmosphere. This, in turn, is the prerequisite for modifying and controlling the weather and climate. In structuring the overview for the Change branch, three major questions must be answered:

1. What changes to state occur in the atmosphere? (Item 6.7.2.3.1).
2. How are these changes related to weather prediction? (Item 6.7.2.3.2).
3. How are these changes related to weather control and modification? (Item 6.7.2.3.3).

The first question leads to another level of questions regarding the local time change of horizontal velocity and temperature. These questions stem from consideration of several of the factors that describe atmospheric state: Momentum and Mass (Item 6.7.2.3.1.1) and Heat (Item 6.7.2.3.1.2). In addition, the effects on the water vapor, cloud, ozone, and aerosol fields by physical transformations and photochemical and advective processes in the atmospheric and at the air-surface boundary relate to questions of changes in Composition and Structure (Item 6.7.2.3.1.3).

The second question, relating to Prediction(Item 6.7.2.3.2), is structured on the basis of differences in time; i.e., it depends on whether a prediction is Short-Range (Item 6.7.2.3.2.1), Extended-Range (Item 6.7.2.3.2.2), or Long-

Range (Item 6.7.2.3.2.3). Three forecast times were defined as follows:

1. Short-range forecasts (Item 6.7.2.3.2.1)-up to 2 days.
2. Extended-range forecasts (Item 6.7.2.3.2.2)-up to 1 week.
3. Long-range forecasts (Item 6.7.2.3.2.3)-more than 1 week.

Terminology and assigned time periods vary within the meteorological community, and there appear to be no uniform, official standards. Therefore, the basis used here was to relate the periods, respectively, to (1) the characteristic period of local change of weather accompanying the passage of baroclinic wave cyclones, (2) the characteristic life span of individual wave cyclones, and (3) periods longer than the wave cyclone life span.

Critical issues (Table 6 of Appendix B) developed under Prediction (Item 6.7.2.3.2) are similar for all three prediction ranges, but they do exhibit some important differences. Changes in the momentum, mass, and temperature fields develop in all forecast periods, but there are unique considerations of local soil heating and local radiation differences for short-range forecasts.

Forecasting techniques are the basis for critical issues for all time periods. Short-range forecasting emphasizes real-time numerical, empirical, and statistical techniques; extended-range forecasting relaxes the timeliness requirement (otherwise using the same basic techniques), but requires a higher precision; long-range forecasting requires the development of new and advanced techniques and supporting technology. Both extended- and long-range forecasting require global observations, whereas the geographical domain for short-range forecasting is much smaller.

The third question developed under Change is that of Modification (Item 6.7.2.3.3). Both purposeful and inadvertent changes are considered. Boundary Processes (Item 6.7.2.3.3.1) and Atmospheric Processes (Item 6.7.2.3.3.2) are considered separately, although some effects, such as radiative changes and colloidal state, relate to both areas. An examination of the critical issues in Table 6 shows that for boundary processes the effects of changing the physical characteristics of the surface and the effects of changing the surface evaporation are important; while in the atmospheric processes, critical issues include modification of the latent heat released by condensation and precipitation, and the effects of changing the aerosol field.

The analysis leading to the present overview for Meteorology developed 64 critical issues in the Knowledge branch. Continuing analysis and exposure of problem areas in Meteorology could eventually result in enlargement of the critical issue list.

2.7.8 Critical Issues for Research

Critical issues identified as a result of the analysis described in Subsections 2.7.1 through 2.7.7 are listed in Table 6 in Appendix B under the subdiscipline headings. The critical issues are numbered with multidecimal serial numbers corresponding to the numbering system of the organized overview.

2.8 REFERENCE MATERIALS

Previous studies of a similar nature were comprehensively reviewed, and their results extensively utilized during the initial phases of this study. Specific references used within each scientific and technological discipline are documented at appropriate points throughout the report. The references listed below were found to be of general applicability and were helpful in imparting a central unity to the analyses of all of the areas.

2-1. Report on the Development of the Manned Orbital Research Laboratory (MORL) System Utilization Potential, Summary Report, Douglas Aircraft Company, Inc., Report SM-48822, January 1966.

2-2. ORL Experiment Program, Volumes A, B, C and D, Federal Systems Division, International Business Machine Corporation, February 1966, contract NASW-1215.

2-3. Orbital Astronomy Support Facility Study, Final Report-Technical Summary, Douglas Report DAC-58141, April 1968.

2-4. Oceanography and Meteorology, A Systems Analysis to Identify Orbital Research Requirements, Douglas Missiles and Space Systems Division, McDonnell Douglas Corporation, April 1968.

2-5. Phase II of a Requirements Study for a Biotechnology Laboratory for Manned Earth-Orbiting Missions, Final Report, Volume I, "Description of Requirements," McDonnell Douglas Astronautics Company, Contract No. NAS1-9248, NASA CR 111794-1, October 1970; Volume II, "Experiment Descriptions," NASA CR 111794-2, October 1970.

2-6. Earth Orbital Experiment Program and Requirements Study, Scientific and Technological Objectives, Report L13-9852, NASA Langley Research Center, 28 July 1969.

2-7. Earth Surveys Program Documentation, Earth Surveys Planning Panel, NASA Planning and Steering Group, 22 October 1969.

2-8. Space Applications Summer Study, 1967 Interim Report, Volume I, National Academy of Sciences-National Research Council, November 1967.

2-9. Useful Applications of Earth-Oriented Satellites, Volume I through 13, National Academy of Sciences, National Research Council, 1969.

2-10. Earth Resources Satellite System, Report for the Subcommittee on NASA Oversight, Committee on Science and Astronautics, U. S. House of Representatives, 90th Congress, 1968.

2-11. Tellurian Resources Inventory and Development (TRIAD), Preliminary Design of an Operational Earth Resources Survey System, 1969 Summer Faculty Fellowship Program in Engineering Systems Design, ASEE-NASA Langley Research Center and Old Dominion University Research Foundation,1969.

2-12. The Role of Manned Spaceflight in Earth Resources Program, NASA Earth Surveys Planning Panel, August 1969.

2-13. Candidate Experiment Program for Manned Space Stations, NASA Document NHB 7150 XX, 15 September 1969.

2-14. Solid Earth and Ocean Physics, Report of the NASA Seminar, Williamstown, November 1969.

2-15. Our Nation and the Sea, Report of the Commission on Marine Science, Engineering, and Resources, January 1969.

2-16. The Post-Apollo Space Program, Directions for the Future, The Space Task Group Report, September 1969.

2-17 Peaceful Uses of Earth-Observation Spacecraft, Volumes I, II, and III, University of Michigan, NASA Contractor Report CR-587, September 1966.

2-18 "Spacecraft in Geographic Research," Report of Conference at NASA Manned Spacecraft Center, Houston, Texas, 28-30 January 1965, Publication 1353, National Academy of Sciences, National Research Council, Washington, D. C., 1966.

2-19 Agricultural Application of Remote Sensing-The Potential from Space Platforms, Agriculture Information Bulletin 328, Economic Research Service, U. S. Department of Agriculture, September 1967.

2-20 R. C. Wilson, Forestry and Range Applications of Remote Sensing Using Earth Orbital Spacecraft, Circa 1980, Forestry Remote Sensing Laboratory, University of California, Berkeley, September 1969.

2-21. Conference with Dr. Robert H. Miller, Agricultural Research Service, U. S. Department of Agriculture, Washington, D. C.

2-22. Conference with Mr. G. A. Thorley, Consultant, Forestry Remote Sensing Laboratory, University of California, Berkeley, California.

2-23. R. J. P. Lyon and E. A. Burns, "Infrared Spectral Analyses of the Lunar Surface From an Orbiting Spacecraft," Proceedings of the Second Symposium on Remote Sensing of the Environment, University of Michigan, October 1962, AD 299 841.

2-24. "Useful Applications of Earth-Oriented Satellites," Summaries of Panel Reports, National Academy of Sciences, National Research Council, 1969.

2-25. Earth Surveys Program Documentation, NASA Headquarters, 22 April 1969.

2-26. Meteorology Subpanel Documentation, Earth Surveys Planning Panel, NASA Headquarters, 17 October 1969.

2-27. The Use of Man in Space Observations, Bellcomm, Inc., October 1969.

2-28. Sensor Definition Study in Support of Unified Space Applications Mission (USAM), prepared by Space Systems Center, International Business Machines Corporation, for NASA Goddard Space Flight Center, February 1968.

Section 3

SCREENING AND GROUPING OF CRITICAL ISSUES

When the critical issues for each discipline were identified, as described in the preceding section, the information required to address each issue was established and the measurement programs necessary to obtain the desired information were hypothesized. The potential characteristics of space activities that would be important in implementing the measurement programs in the various research areas were then examined and the critical issues for which the contribution of a space platform could be indicated were identified.

Research activities that were determined to be relevant for space platforms were in turn considered for their appropriateness to manned research facilities.

For those critical issues that appeared to be candidates for manned platforms, ongoing and planned programs were reviewed and the relationships of candidate research activities to these programs were established. The critical issues that were not being addressed by current programs but were relevant to manned orbital platforms served as the base for the remainder of the analysis.

It was determined early in the analysis that the critical issues with common data or measurement needs and similarities in experimental approach could be grouped or clustered into meaningful units. These "research clusters" provided the basis for the more definitive expression of facility and operational requirements documented in later portions of this report.

The overall process and the criteria by which the critical issues were screened and reduced to clusters of experiments with similar researc[illegible]quirements are described in this section.

3.1 GENERAL METHODOLOGY FOR SCREENING OF CRITICAL ISSUES

In the initial identification of critical issues, areas in the various disciplines clearly not related to space platforms or clearly outside of stated NASA goals and objectives were automatically rejected by the study team. Areas rejected included such diverse topics as the theoretical development of mathematical models, questions of purely political or jurisdictional nature, or the development of specialized facilities or capabilities such as food-processing equipment for floating fish canneries. Care was taken by the study team, however, to keep as broad an approach as possible in each discipline to ensure against the premature elimination of critical issues that might, under more thorough examination, warrant inclusion in a comprehensive orbital research program.

Thus, the items that appear in Tables 1 through 6 in Appendix B reflect a conservative and rational approach to the identification of critical issues which are potential candidates for consideration in orbital research programs.

In sequential stages, the critical issues of potential importance in space platforms were examined to eliminate inappropriate items. The screening of the remaining critical issues was performed in three steps. First, issues for which research in orbit would be appropriate were separated from those for which ground-based, airborne, or other locations would be feasible. Second, from among the space-applicable critical issues, those for which the participation of man in orbit would be appropriate were identified on the assumption that manned space platforms devoted to research activities would be available for these operations. Third, the contributions of other programs that might already have provided or be in the process of providing the information asked for by any of the critical issues were accounted for. The criteria and procedures appropriate to these three screening steps are discussed in the following subsections. The application of the screening process and the specific grouping of critical issues into research clusters in six disciplines are described in later subsections.

3.1.1 Screening for Space-Research Applicability

In selecting critical issues as candidates for space research, as distinguished from nonspace research, characteristics of both earth orbits and the space environment were examined. This examination helped in determining the advantages or disadvantages of conducting any given type of experiment from an orbital space platform.

3.1.1.1 Orbital Characteristics

An earth-orbiting vehicle, if it has a sufficiently high altitude or if it has the propulsion needed to overcome orbit decay, may have a lifetime in orbit of months or years. Orbits with high inclinations may have the capability of complete global coverage. Orbit parameters can also be selected to:

A. Allow an infinite choice of coverage patterns, including dense coverage of any area of interest on the earth's surface;

B. Repeat themselves periodically, including, if desired, repeated viewing of the same features with the same illumination and solar angles;

C. Allow viewing of surface features from a variety of aspect angles or directions;

D. Allow the best compromise between a broad field of view, acceptable resolution, orbit decay, and the radiation environment;

E. Allow data accumulation and storage over selected areas and the telemetering of these data to selected ground stations.

Matrices displaying the influence of the pertinent orbital characteristics on various critical issues were used by the study team as an aid in the screening. The general arrangement of these matrices, in simplified form, is shown in Figure 3-1. The specific working matrices used in the actual screening are included in Subsections 3.2 through 3.7.

The orbit and space environment parameters, some of which are indicated in Figure 3-1, were the principal criteria used in defining space and nonspace categories for any critical issue. The orbital characteristics identified in Figure 3-1 were used to determine how the flight mechanics factors influence a research activity or critical issue; that is, which opportunities are available, considering the orbital constraints. Similarly, the space environment factors identified in Figure 3-1 (and discussed in Subsection 3.1.1.2) were used to determine the manner in which the environment of space influences research addressed to the critical issues.

Factors considered in examining the advantages of orbital operations are discussed in the following paragraphs.

E = ESSENTIAL
H = HELPFUL
N = NO EFFECT
T = TOLERABLE
I = INTOLERABLE
U = EFFECTS UNKNOWN

	ORBITAL CHARACTERISTICS					SPACE ENVIRONMENT CHARACTERISTICS							
	BROAD FIELD OF VIEW	GLOBAL COVERAGE	TARGET SELECTION OPPORTUNITIES	ORBITAL VELOCITY	REPEATABLE GROUND TRACK	PARTIAL-OR ZERO-GRAVITY EFFECTS	SPACE VACUUM	METEOROIDS	ATMOSPHERIC ATTENUATION	COSMIC RADIATION	RADIATION BELTS	CRITICAL ISSUE SUITABLE FOR SPACE (√)	(CONTINUED IN FIG. 3-17)
CRITICAL ISSUE 1	N	H	E	N	N	N	N	T	E	T	N	√	
CRITICAL ISSUE 2	E	E	N	N	H	N	N	T	N	N	N	√	
•													
•													
•													
CRITICAL ISSUE N	N	N	T	T	H	N	N	N	T	N	N	—	

Figure 3-1. General Format of Matrix Display of Influence of Orbital and Space Environment Characteristics on Critical Issues

Broad Field of View

Various earth-oriented orbital geometries were examined (Figure 3-2) to assess the effects of orbital characteristics upon the viewing potential from spacecraft, particularly with respect to earth observation research activities.

Global Coverage

In analyzing those critical issues where aerial coverage is important (such as agricultural research), the parametrics in Figure 3-3 were used to help determine the orbital requirements for obtaining the desired surface coverage.

Target Selection Opportunities

In observations of earth resources, the effect of cloud cover on selection of ground targets is of particular interest. Clouds are opaque in both the visible and IR regions of the spectrum, so that cloud cover alone is the determining factor for earth observations using those wavelengths. Table 3-1 presents cloud distribution data for two selected locations.

Microwave propagation through the atmosphere is also affected by cloud cover, through both scattering and absorption, but this region of the spectrum does offer "all weather" capabilities of a limited nature. Combining the cloud-cover climatology with scattering and absorption characteristics facilitated reasonable estimates of microwave viewing capability.

Orbital Velocity

Figures 3-4, 3-5, and 3-6 describe parametrically ground trace velocity limits and flightpath velocity limits of spacecraft as a function of apogee and perigee altitude. These data were used to assess advantages and disadvantages of obtaining data from orbit.

Repeatable Ground Track

In certain cases (such as marine biological studies), observations need to be made at discrete intervals of time (temporal resolution). To assess the ability of a spacecraft to synchronize its orbit with these observations, data of the type shown in Figure 3-7 were used.

3.1.1.2 Environmental Characteristics

Information was obtained on the space environment to facilitate the analysis of environmental characteristics. Because of the continual updating of this type of information, efforts were made to utilize the most recent sources available. The sources used are cited where appropriate in the following paragraphs.

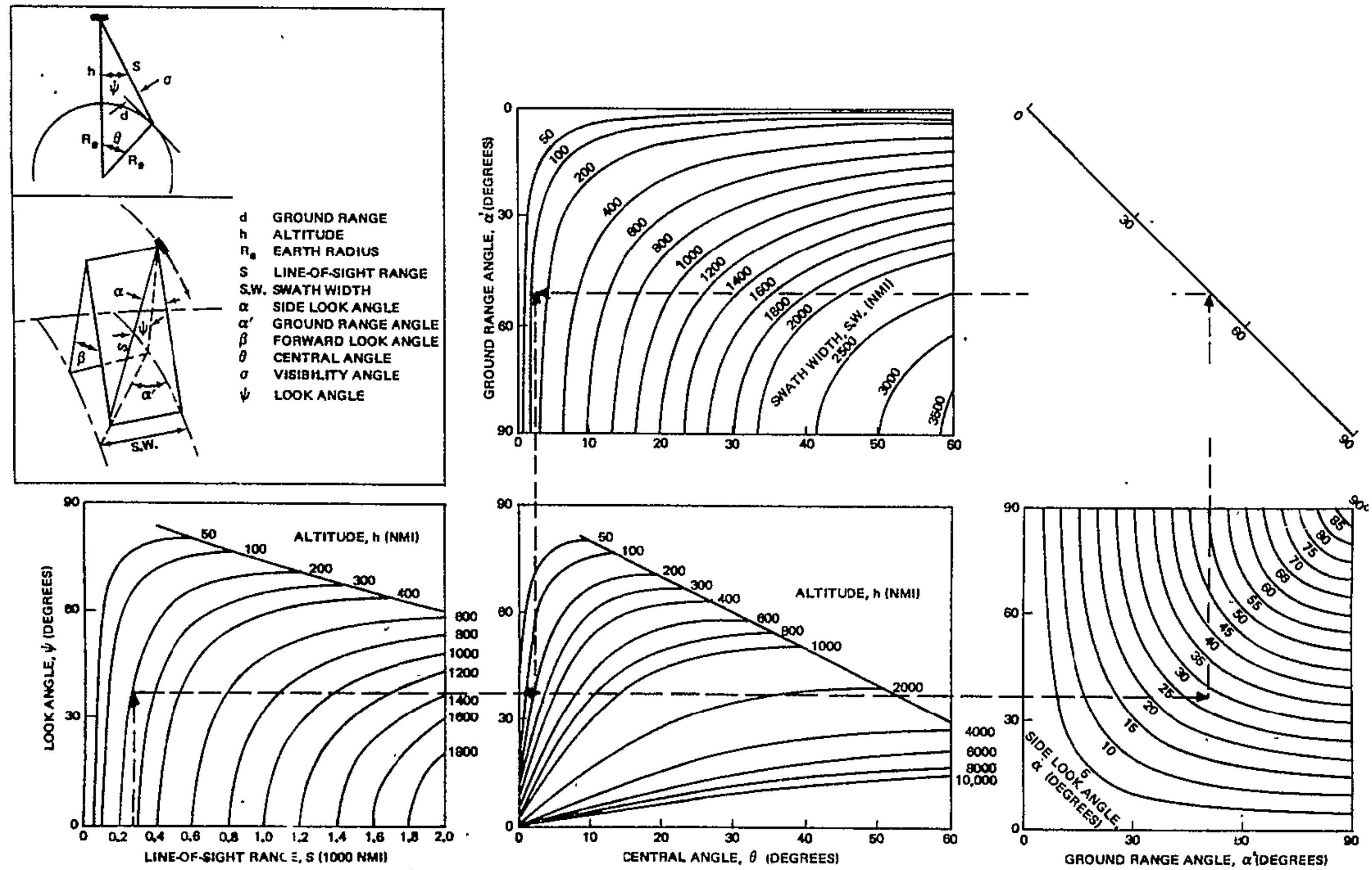

Figure 3-2. Nomograph for Consistent Values of Altitude, Range, Swath Width, and Related Parameters

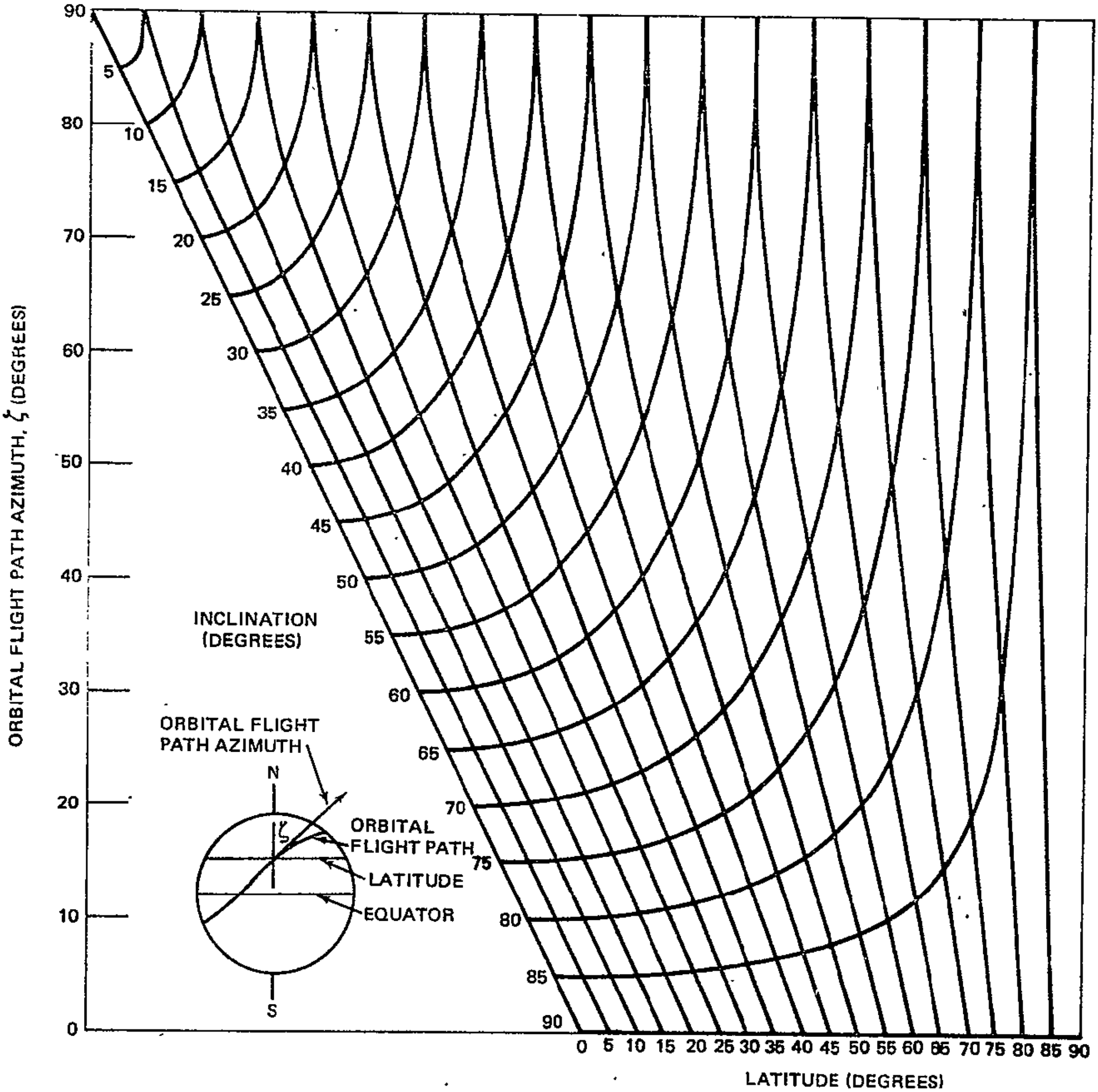

Figure 3-3. Orbital Flight Path Azimuth

Table 3-1

OCCURRENCE OF VARIOUS FRACTIONS OF CLOUD COVER AT SELECTED LOCATIONS AND TIMES
(Percent of Time at Given Fraction)

Location	Fraction of Cloud Cover	January, Midnight Local Time	January, Noon Local Time	July, Midnight Local Time	July, Noon Local Time
32.5°W 42.5°N	0/8	0.3	0	0	0
	1/8	1.8	0	2.9	0.2
(North Atlantic shipping lanes)	2/8	2.2	1.0	8.3	3.6
	3/8	8.6	2.4	18.6	15.3
	4/8	15.2	5.9	13.2	17.3
	5/8	10.5	14.3	22.2	16.6
	6/8	16.0	22.4	16.8	17.1
	7/8	24.6	30.9	12.6	22.6
	8/8	20.8	23.1	5.4	7.3
177.5°W 47.5°N	0/8	0	0	0	0
(North Pacific shipping lanes)	1/8	0.5	0.5	0	0
	2/8	3.9	1.7	0	0
	3/8	7.6	1.4	0	0
	4/8	10.4	10.9	0	1.2
	5/8	12.5	13.0	0	1.6
NOTE: July has the year's worst weather at this location.	6/8	19.3	25.5	0.1	9.0
	7/8	22.6	19.8	5.7	15.9
	8/8	23.2	27.6	94.2	72.4

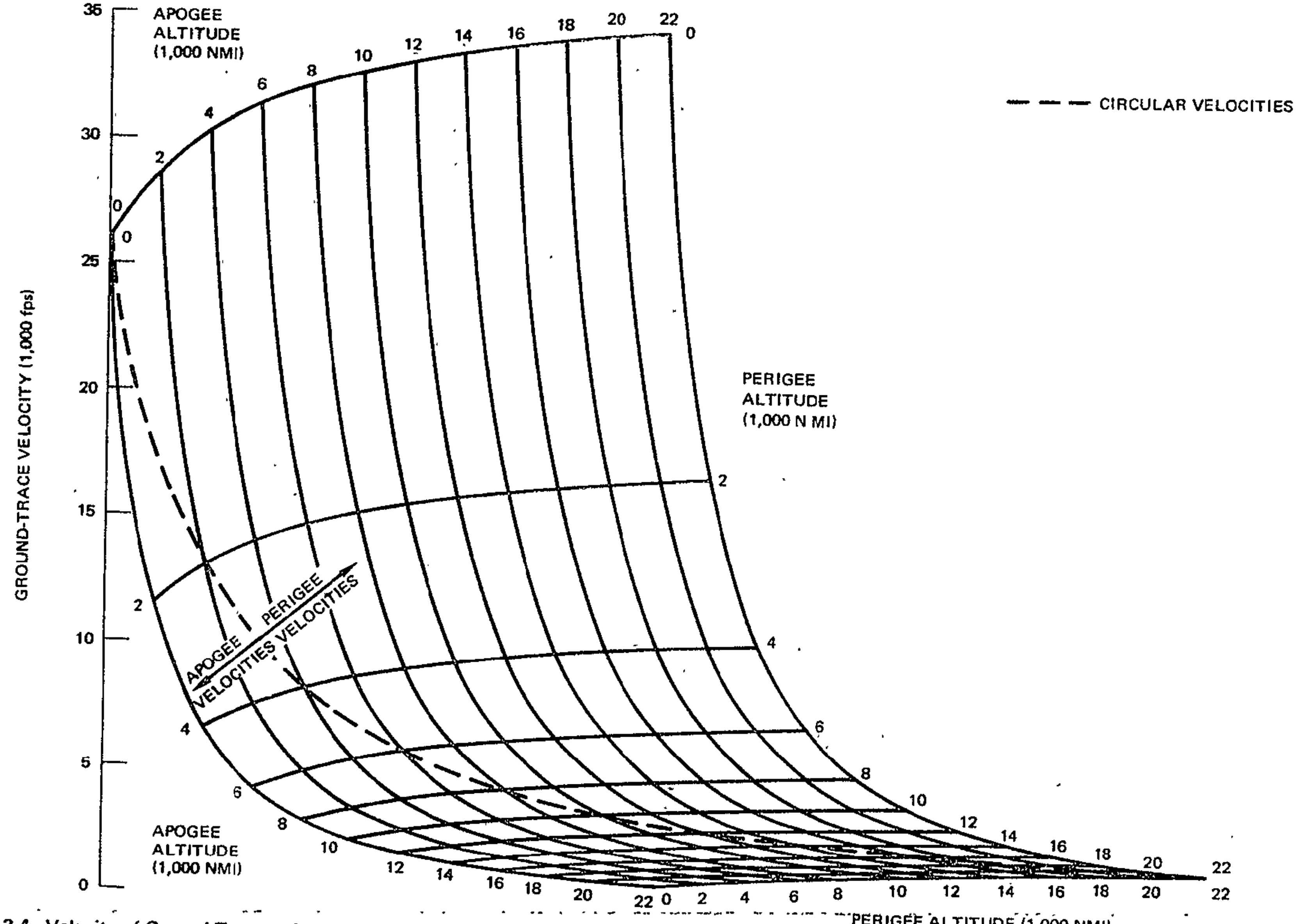

Figure 3-4. Velocity of Ground Trace at Apogee and Perigee as a Function of Apogee and Perigee Altitudes – Non-Rotating Earth

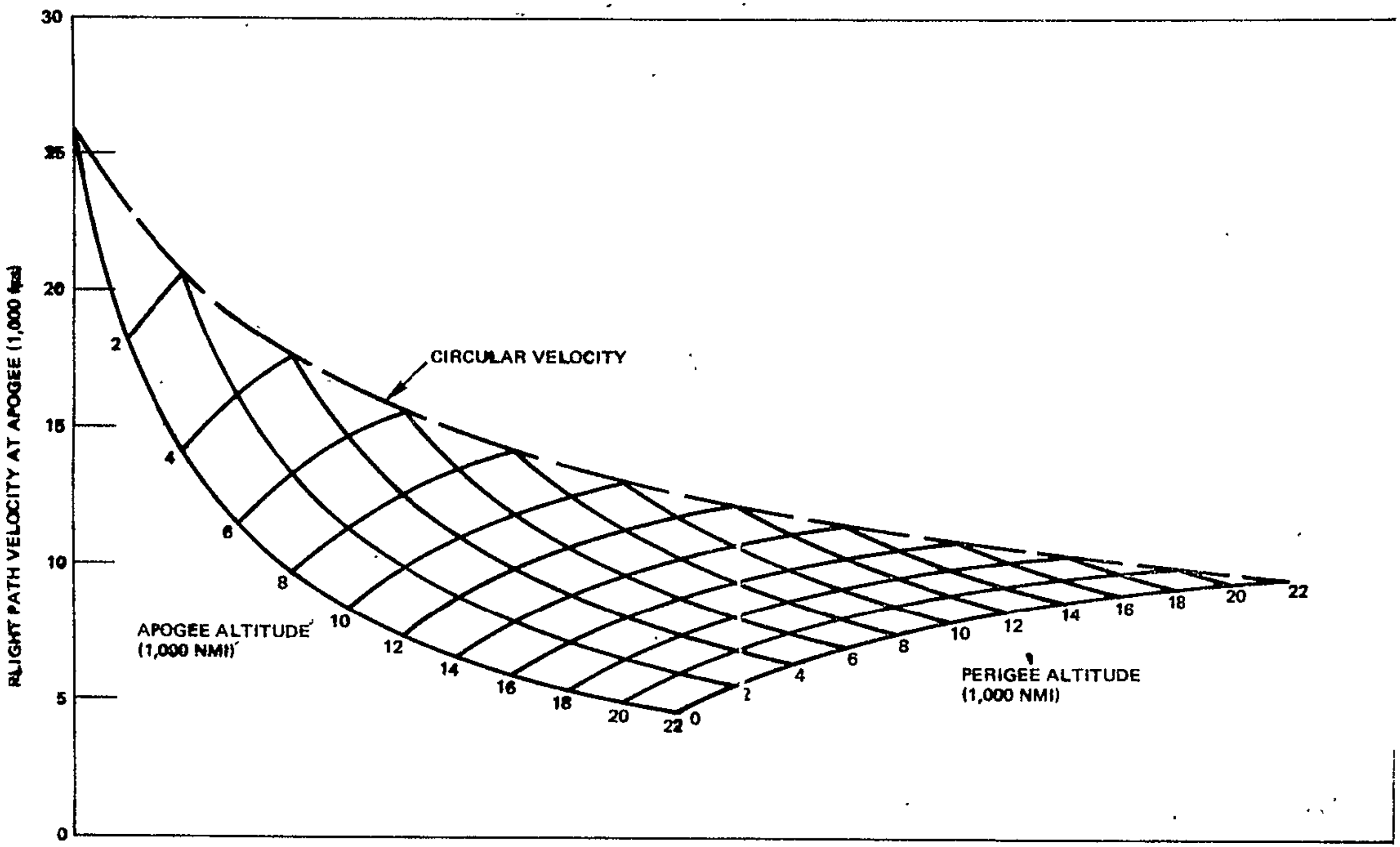

Figure 3-5. Flightpath Apogee Velocity as a Function of Apogee and Perigee Altitudes

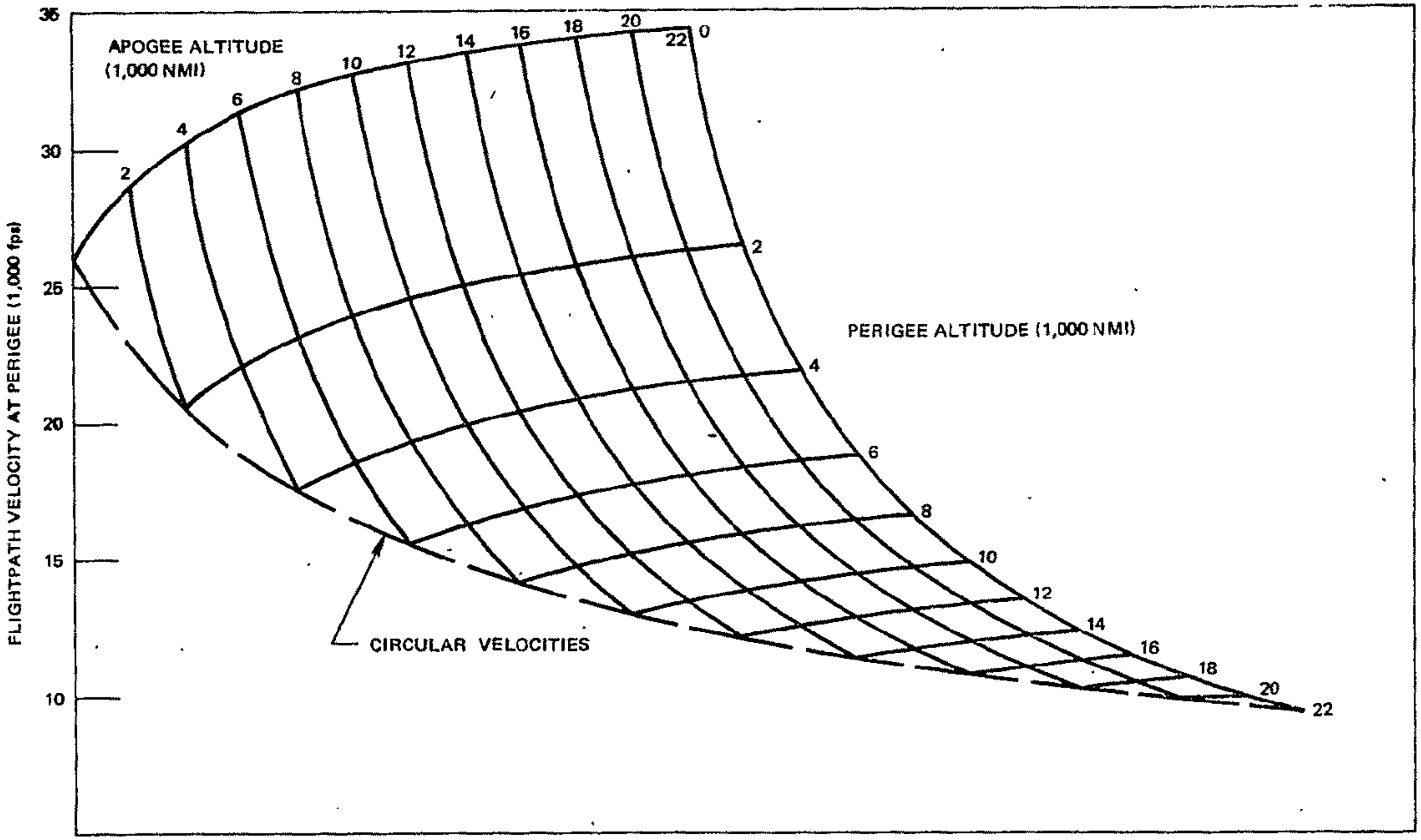

Figure 3-6. Flightpath Perigee Velocity ‹ s a Function of Apogee and Perigee Altitudes

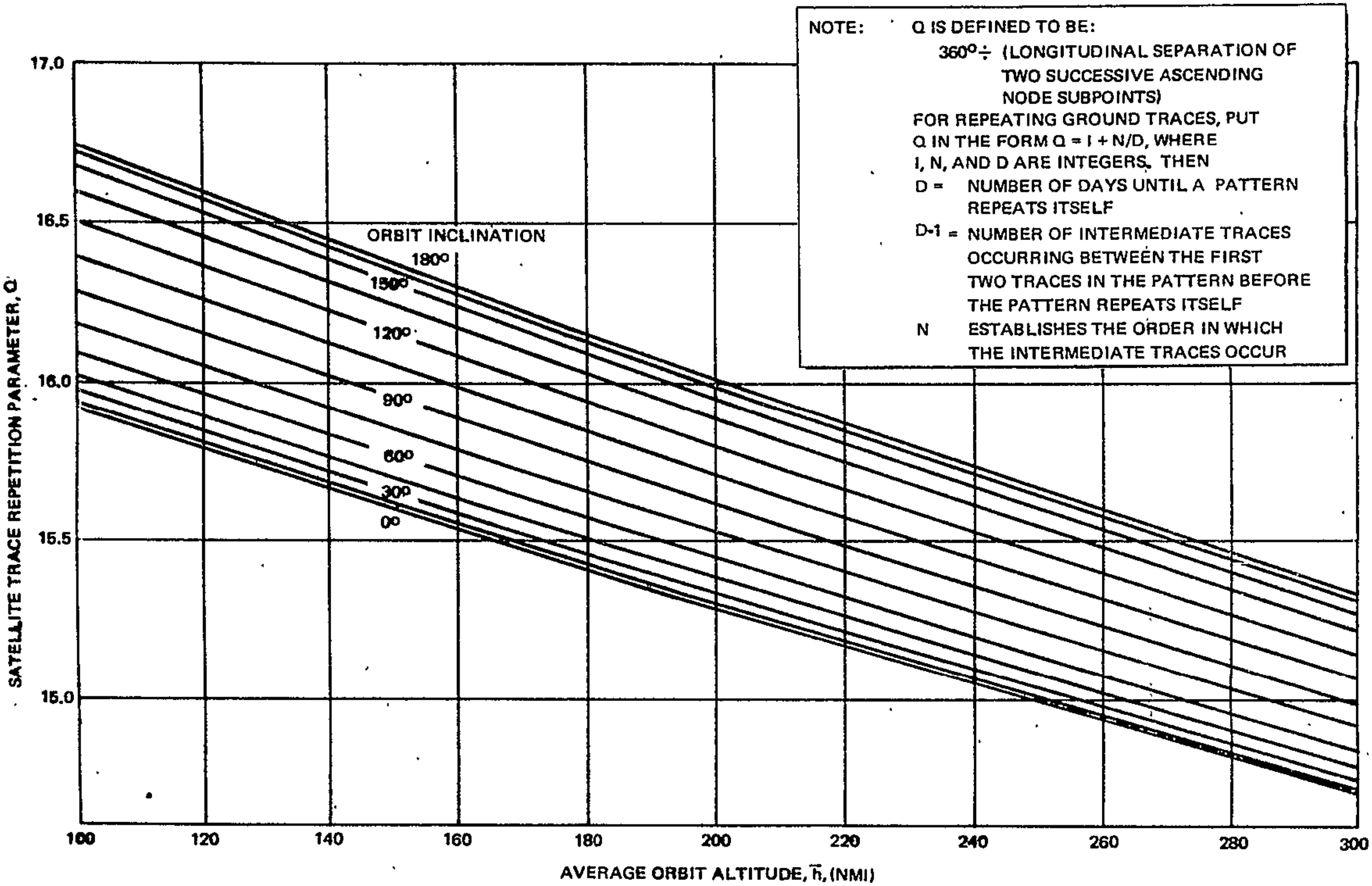

Figure 3-7. Satellite Trace Repetition

Partial- or Zero-Gravity Effects

Earth-based platforms (drop towers) and aircraft offer a very limited capability for providing a zero-g or weightless environment. For research programs in which weightlessness must be maintained below 1-g levels for extended periods of time, space platforms become a necessity.

Space Vacuum

The atmosphere at altitudes of 100 n.mi. or higher is sufficiently rarefied to facilitate vacuum-dependent research. However, its density varies considerably over a range of values of altitude, time of day, solar flux, and inclination. Measurements of atmosphere density taken in different research programs have produced several atmospheric-density models which unfortunately are not consistent with one another.[1,2] Current atmospheric models correlate fluctuations in the upper atmosphere with an index of solar flare activity. Solar UV heating of the upper atmosphere is correlated with decimeter (wavelength) solar flux, the best correlation being found at 10.7 cm wavelength. Predictions of solar activity, including the 10.7-cm solar flux, are periodically made by the Space Environment Branch, S & E-AERO-YS, Marshall Space Flight Center, Alabama. A prediction for the next solar cycle is presented in Figure 3-8. The wide probability range in this figure demonstrates the general level of uncertainty in these predictions. Figures 3-9 through 3-14 illustrate the variation of density with time of day for various levels of solar flux. Most of these figures were derived from the atmospheric model. As the solar flux prediction is imprecise, and because there is a variance in the different atmospheric models (see Figure 3-14), these data were used with caution.

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1. Theoretical Models for the Solar-Cycle Variation of the Upper Atmosphere. NASA TND-1444, August 1962.
2. O. K. Moe. A Review of Atmospheric Models in the Altitude Range 100 to 1000 KM. AIAA Paper No. 69-50, January 1969.

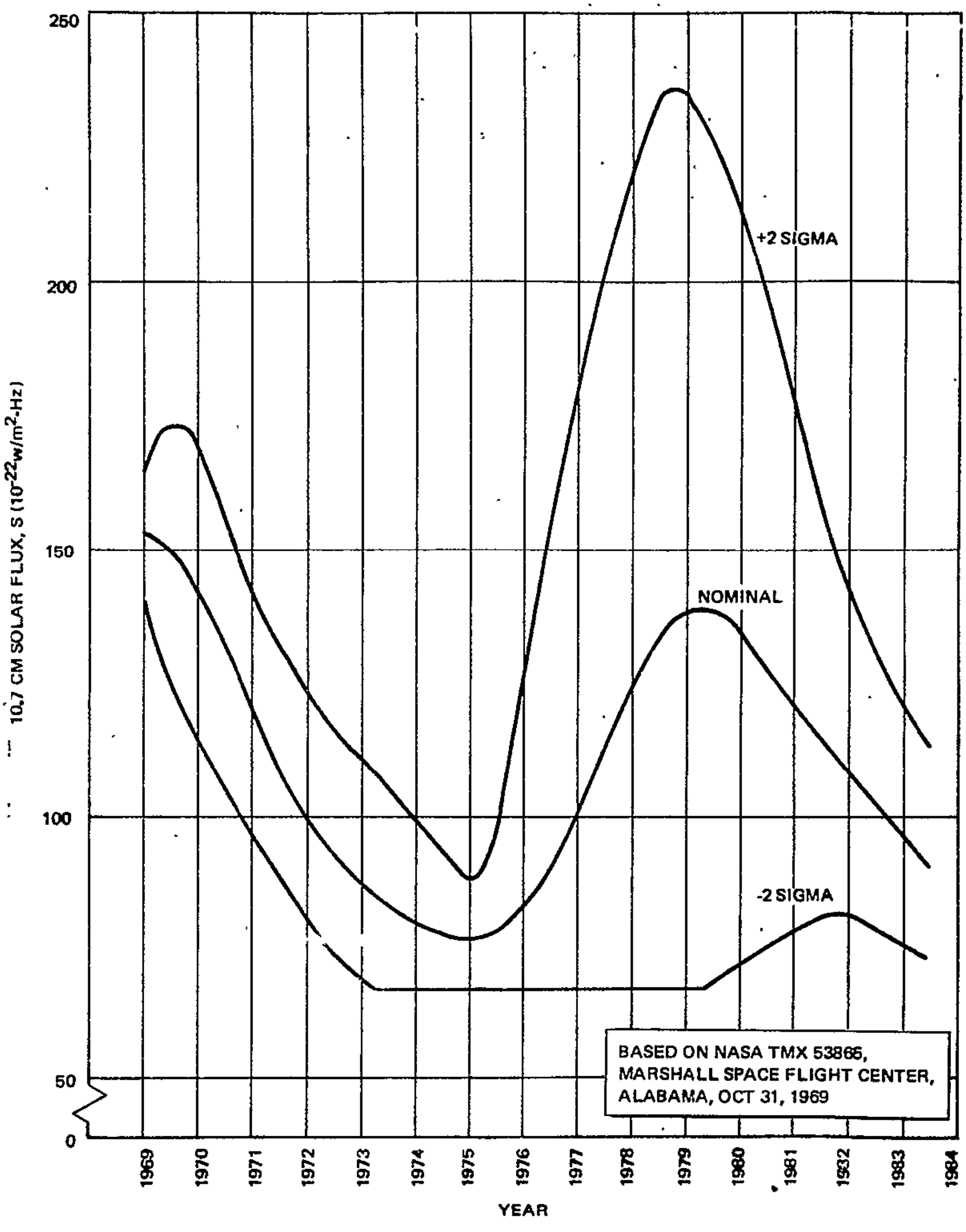

Figure 3-8. Predicted Solar Flux (10.7 cm Wavelength)

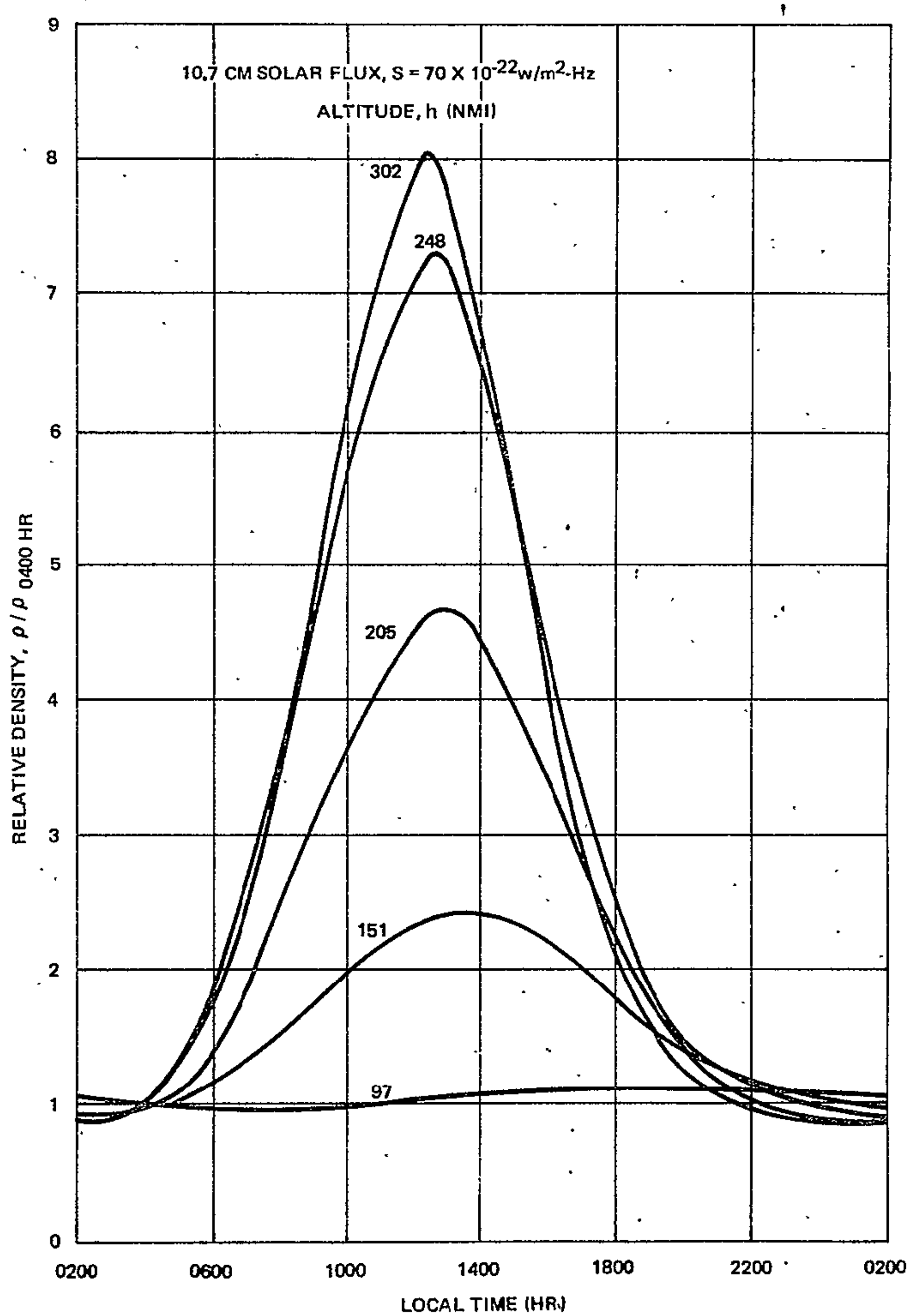

Figure 3-9. Density Variation with Time of Day, S = 70

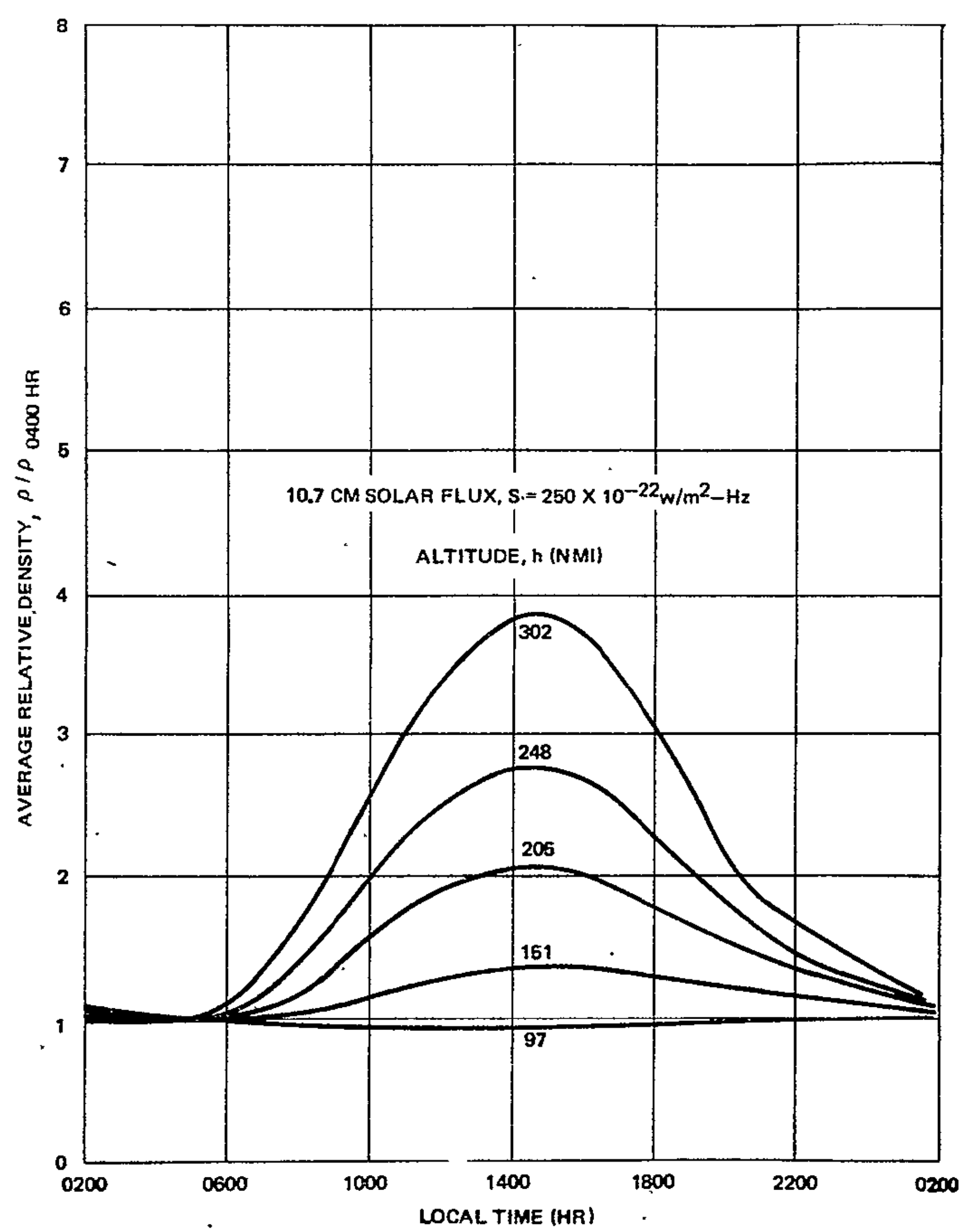

Figure 3-10. Density Variation with Time of Day, S = 250

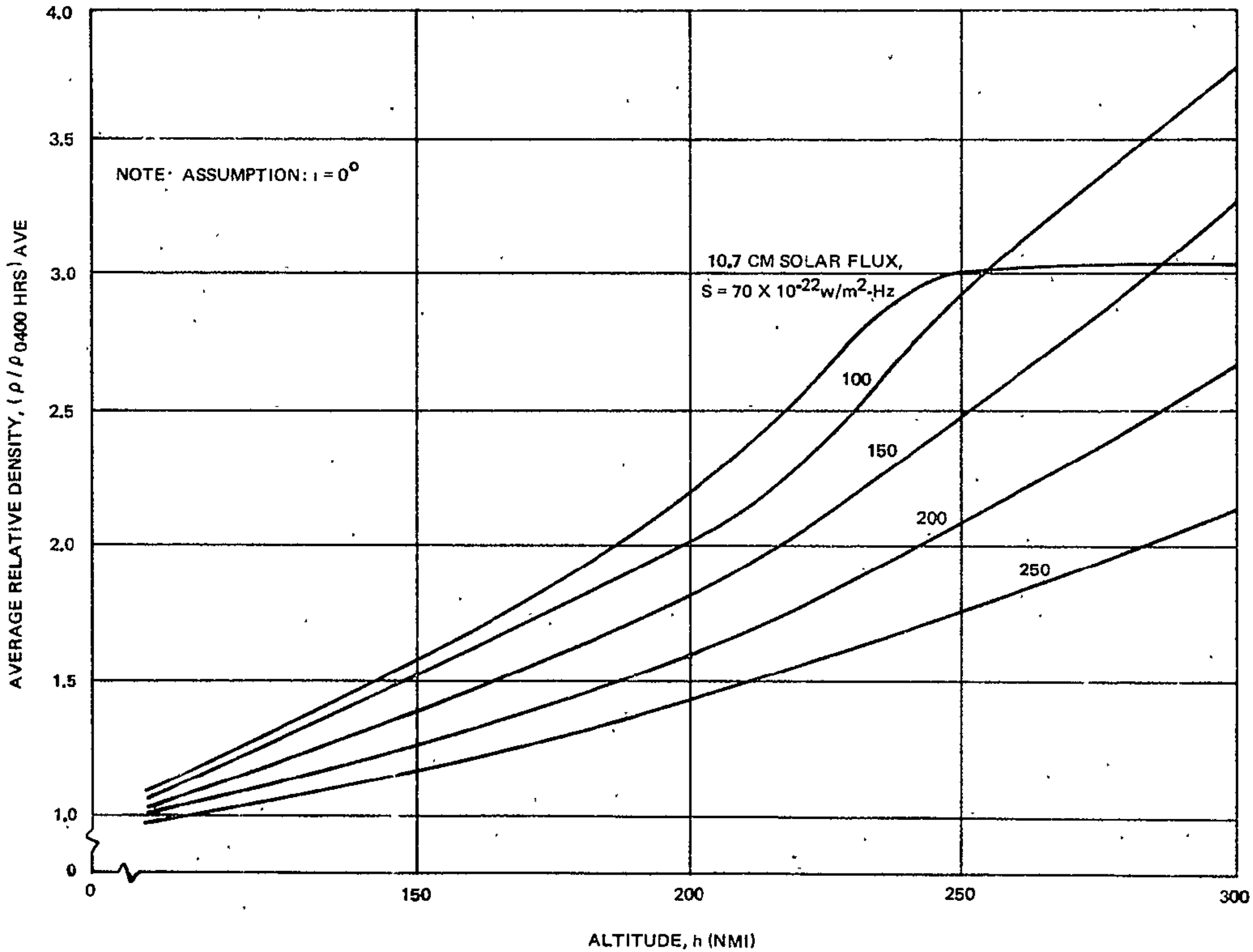

Figure 3-11. Effect of Solar Flux on Average Relative Density (Diurnal Bulge Effect)

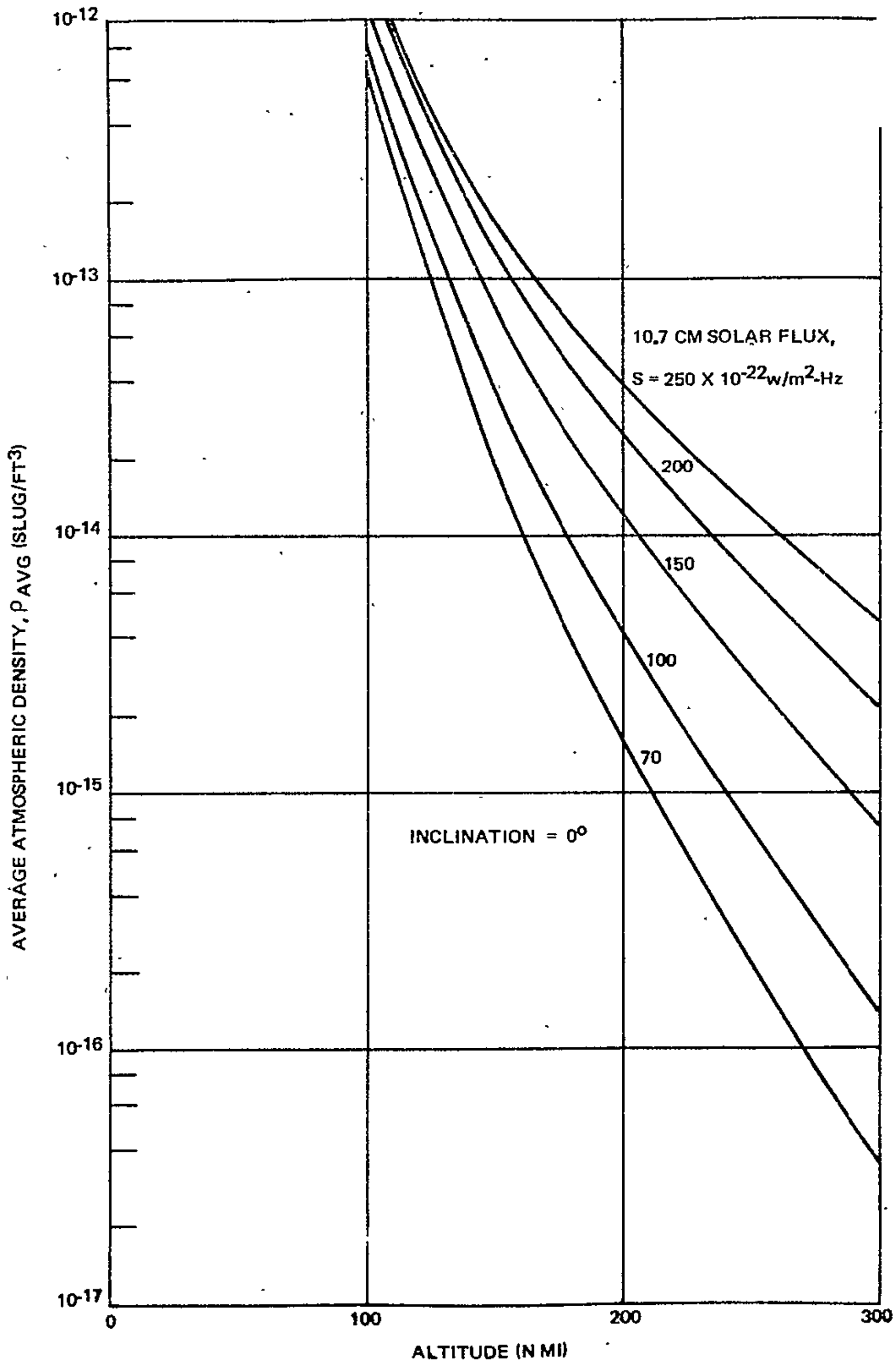

Figure 3-12. Average Atmospheric Density Encountered in Circular Orbits

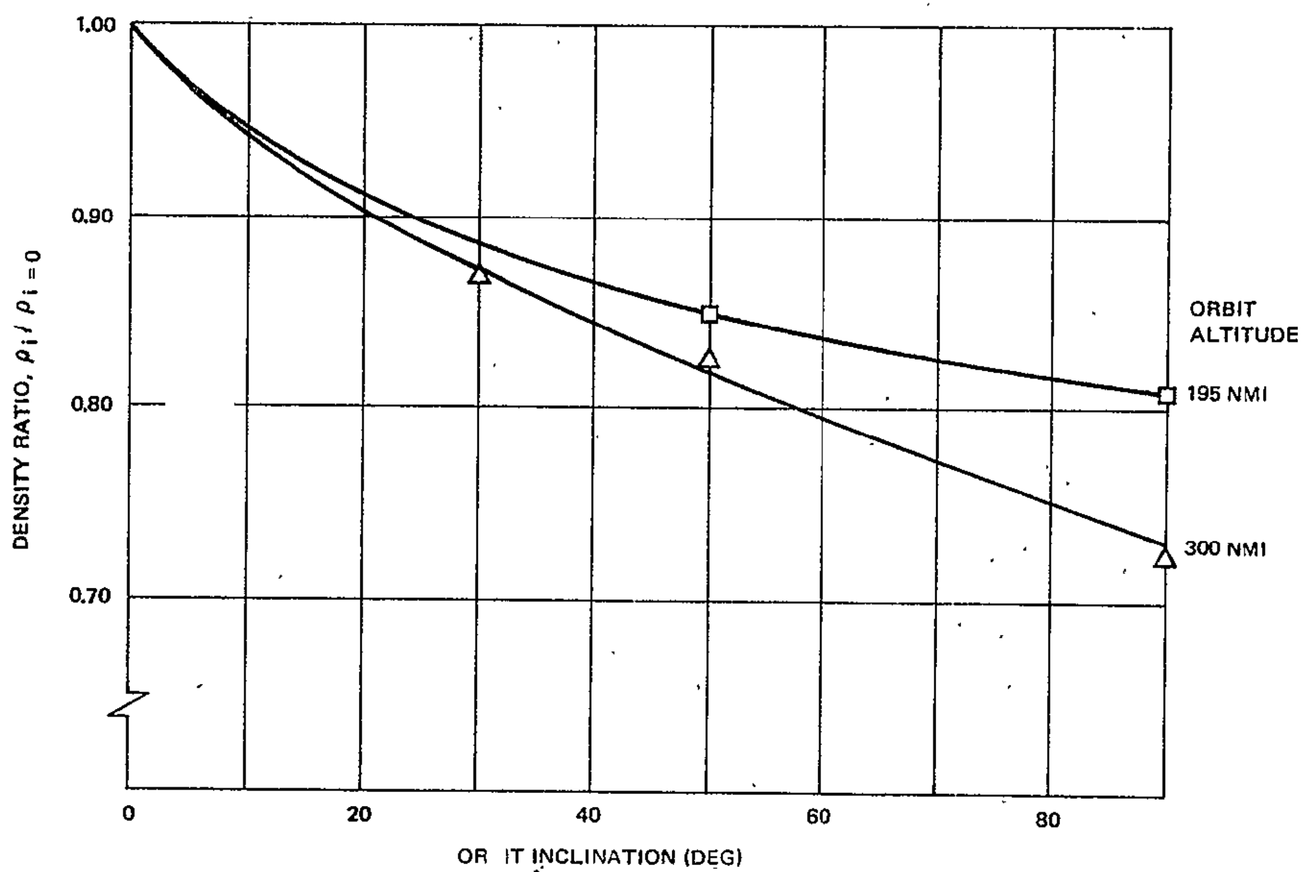

Figure 3-13. Effect of Orbit Inclination on Average Atmospheric Density Encountered

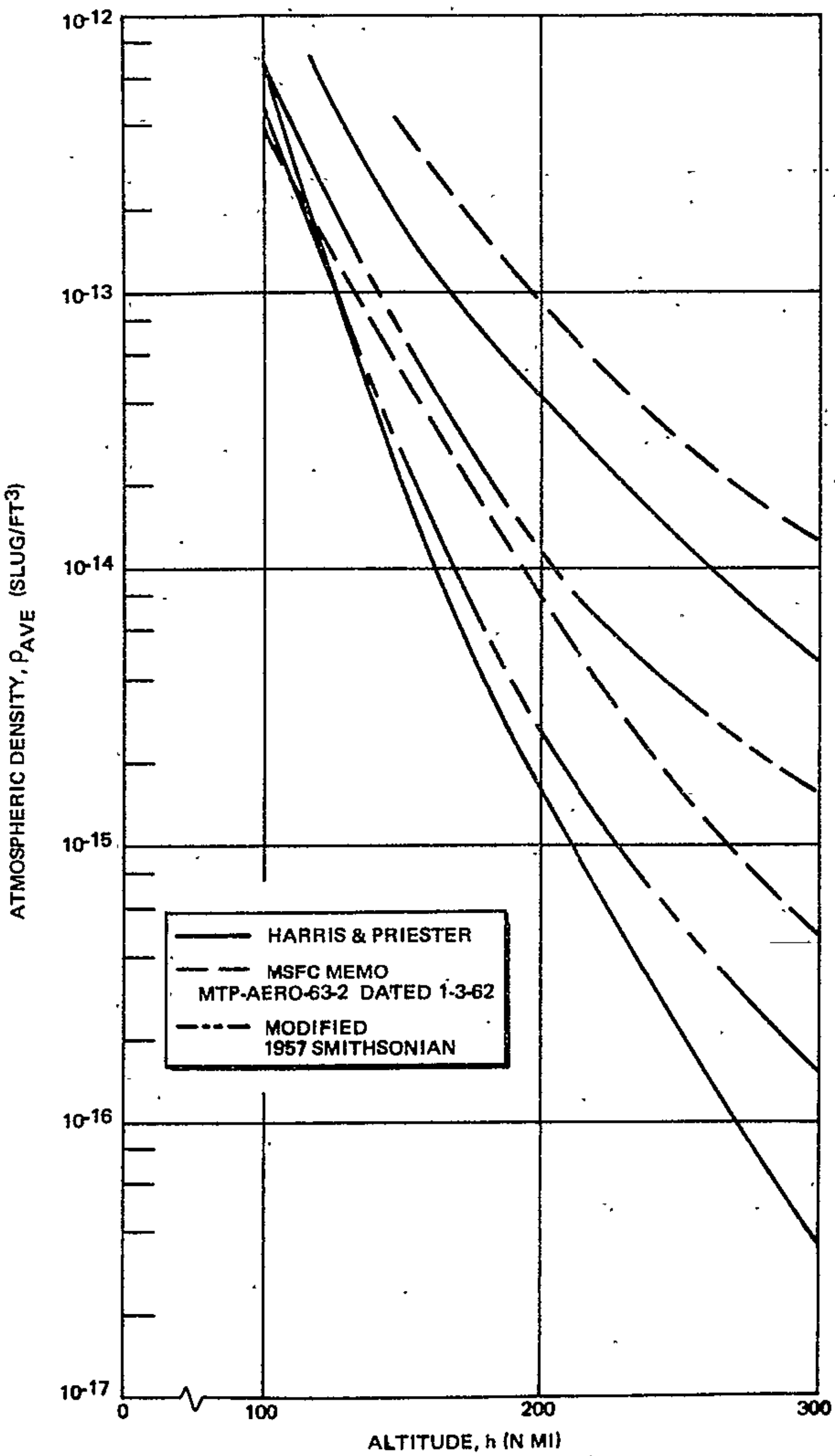

Figure 3-14. Extremes of Atmospheric Density Given by Several Atmospheric Models

Meteoroids

Damage by meteoroids is a potential hazard in space. With shielding, an orbiting vehicle gains protection from this hazard. However, research activities that require unshielded equipment for experiments—even if these activities are conducted for relatively short periods of time—must make allowances for the meteoroid environment.

Meteoroids originate from both cometary and asteroidal sources. In the region of 1 A.U., the contribution of asteroidal particles to the total meteoroid population is considered to be negligible.* This precludes stoney meteoroids with densities of at least 2.5 gm/cm^3.

A simplified model of the meteoroid environment is presented in Figure 3-15. A density of 0.5 gm/cm^3 is assumed in the model, although values have been calculated from observations which range from 0.16 to 4 gm/cm^3. Cometary meteoroid velocities at atmospheric entry range from 8 to 75 km/sec with an average velocity of about 20 km/sec.

Atmospheric Attenuation

The transmission characteristics of the earth's atmosphere (Figure 3-16) are such that portions of the electromagnetic spectrum are attenuated when the celestial sphere is viewed from the earth or, conversely, when the earth is viewed from a space platform. In particular, orbiting vehicles offer distinct advantages for astronomical observations. For observations of the earth from orbit, the spectral "windows" in the visible, near IR, and microwave regions will prove of great value.

Radiation Effects

The radiation environment of an earth-orbiting satellite consists of galactic cosmic rays, solar cosmic rays, and charged particles and electrons trapped in

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*Meteoroid Environmental Model - 1969 (Near Earth to Lunar Surface), March 1969 (preliminary copy).

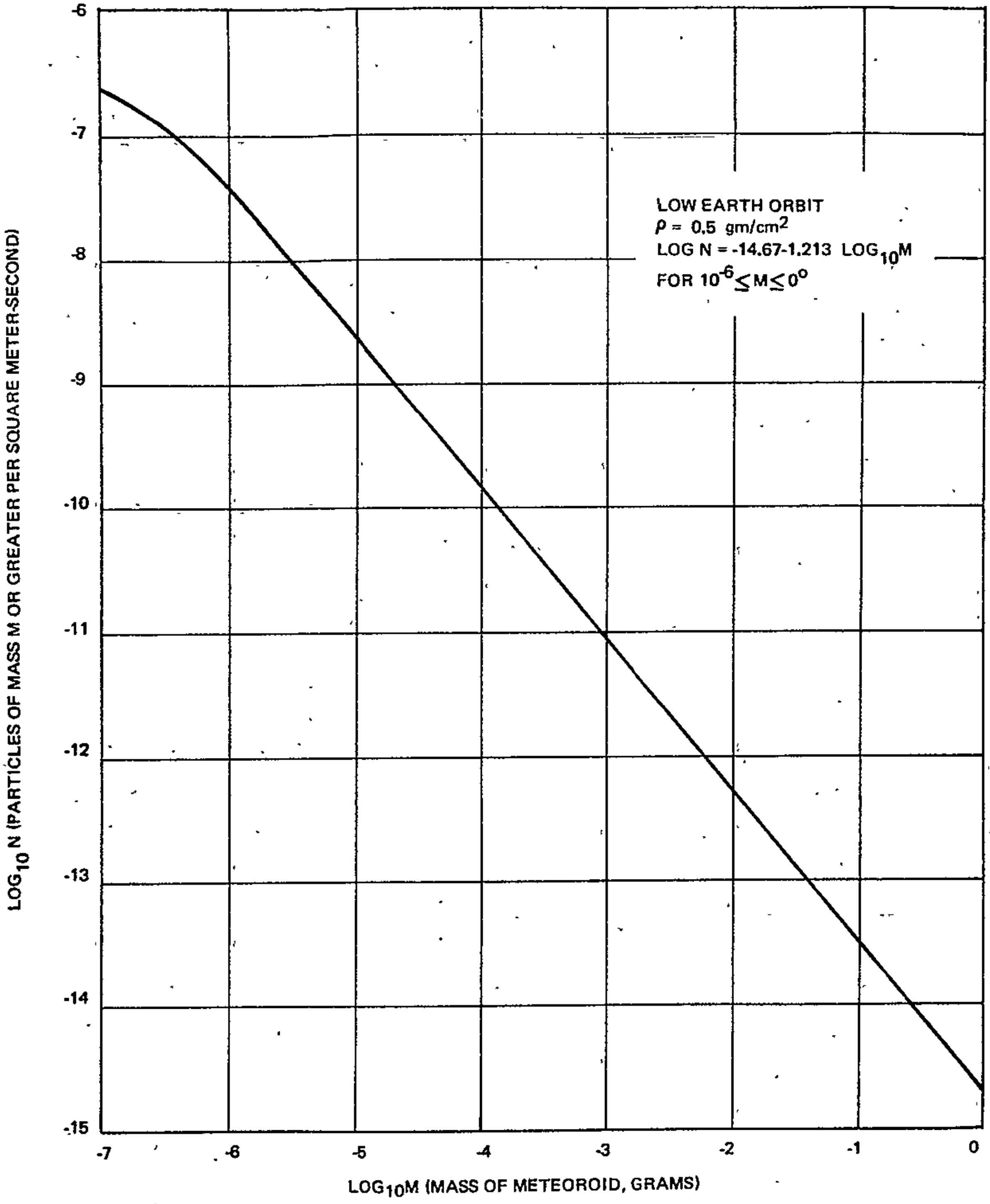

Figure 3-15. Meteoroid Environment

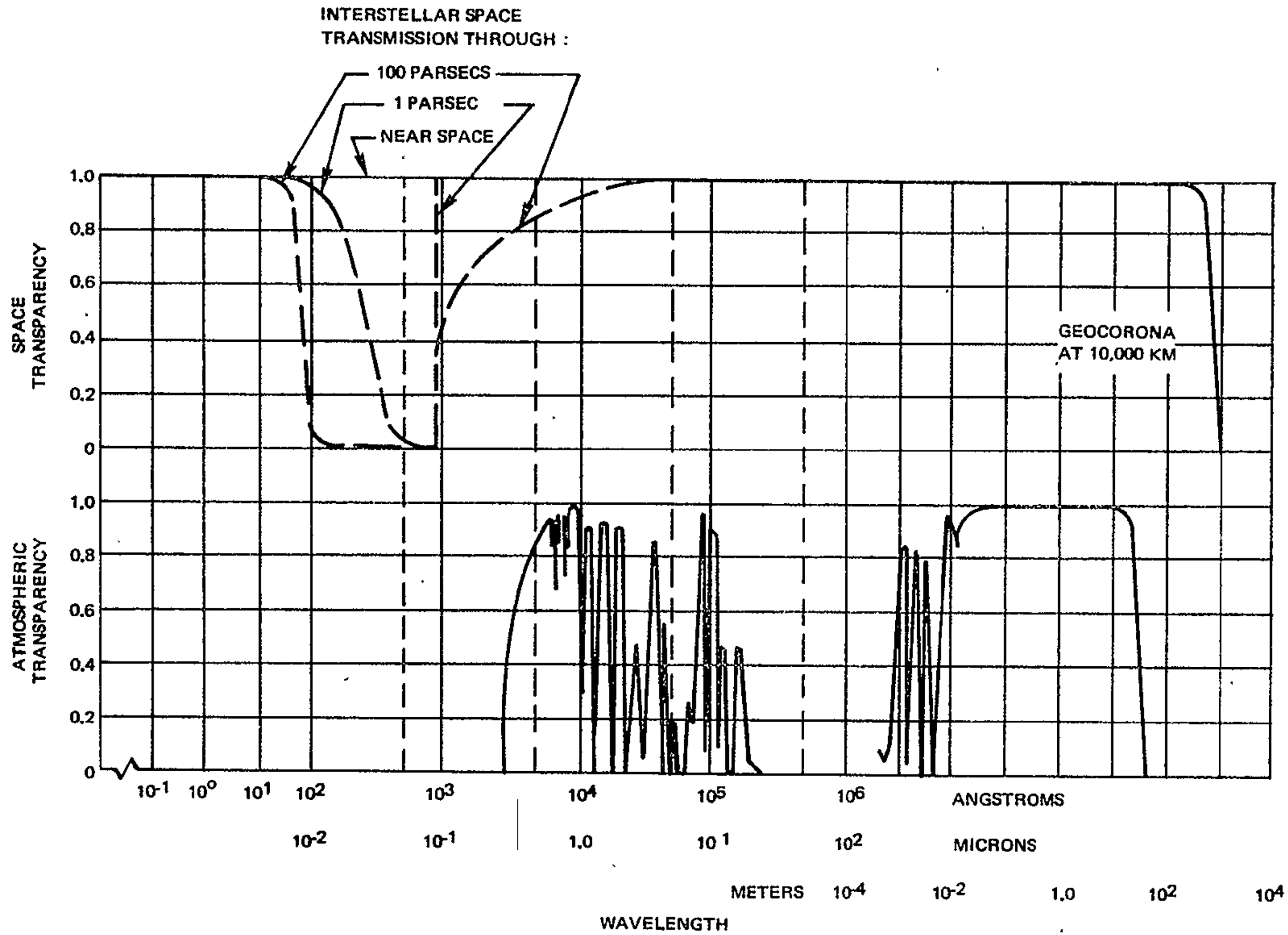

Figure 3-16. Electromagnetic Energy Transmission Through the Earth's Atmosphere and Through Space (Vertical Path)

the earth's magnetic field (Van Allen belts). Radiation can be hazardous to man, to other biological matter, to photographic film, and to electronic equipment. Radiation flux varies as a function of solar activity, altitude, latitude, and (because of a geomagnetic anomaly) longitude. A NASA report* was used as the basic reference to provide information for assessing the impact of space radiation on each research area.

Galactic cosmic rays are composed of approximately 85 percent protons, 14 percent alpha particles, and 1 percent heavier atomic nuclei. The free-space proton flux varies with the 11-year solar cycle; the flux is about 2.5 protons/cm^2-sec at solar maximum and about half that amount at solar minimum.

At high altitudes and at high latitudes, the galactic and solar cosmic rays are the major contributors of radiation. At lower altitudes and latitudes, the earth's gravitational field shields against cosmic radiations, and the trapped particle and electron radiations of the Van Allen belts are the major radiation contributors.

Regarding solar cosmic radiation, a NASA report states that "the radiation intensity from solar flare activity follows an approximate 11-year cycle with enormous flux variations ranging from about 10^5 protons/cm^2 at solar minimum to approximately 10^9 protons/cm^2 per flare at solar maximum for protons with energy above 30 MeV. Solar cosmic radiation has two main components—protons and alpha particles—in a proton-to-alpha ratio varying from 1 to 100. There is also a minor component of heavier nuclei which makes up about 0.1 percent of the total."*

Solar flares can be predicted only as probabilistic events in relation to sunspot activity. Their relatively safe periods and relatively hazardous periods can be predicted, but a given flare cannot be predicted. During a solar flare,

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* An Analysis of the Energetic Space Radiation and Dose Rates. NASA TN-D-4404. Feb. 1968.

however, its severity can be predicted, and precautions can be exercised. A proton shower may have a flight time from sun to earth of from 1/2 hour to approximately 12 hours. There is a characteristic profile of intensity as a function of time for a solar flare. The solar cosmic ray flux increases exponentially to a maximum and then decays exponentially. Proton showers can be detected from flares and their intensities can be predicted during the flux increase stage. There is no basis, however, for assuming that the flares observed so far represent the maximum energy spectrum of future solar flares.

The energy of cosmic rays or solar flare protons is attentuated by the magnetic field of the earth in a manner characterized by a vertical cutoff energy. The penetration of charged particles from cosmic rays or solar flares into the earth's magnetic field is dependent upon the energy of these particles as shown in the following formula

$$E_c = -938 + \sqrt{(938)^2 + \frac{2.25 \times 10^8 \cos^8 \lambda}{R^4}}$$

where a proton of the vertical cutoff energy, E_c, approaching the center of the earth (i.e., from the zenith) at geomagnetic latitude λ will be stopped by the earth's magnetic field at R earth radii from the center of the earth. The vertical cutoff varies with solar active periods.

In the Van Allen belts, the charged particles constrained by the earth's magnetic lines of force move in helical paths around and along these lines of force, being mirrored, at the high latitudes, north to south and back again in continuous oscillation. Another characteristic is that they drift or rotate longitudinally. The inner Van Allen belt ranges from about 500 to 600 n.mi. where interaction with the atmosphere occurs, to higher regions (about 1 earth radius) where the earth's magnetic field is relatively stable and few interactions occur. The outer Van Allen belt is in a still higher region (on the order of 2 to 3 earth radii at the equator), where the earth's magnetic field is affected by temporal solar phenomena and where particles from solar flares may be captured in the belt.

The proton flux encountered by an orbiting satellite, integrated over a day's time, is dependent upon its altitude and inclination. The variation of flux of a single orbit is dependent upon geomagnetic anomalies and orbital parameters.

Electron flux is also present in the radiation belts. The primary electron environment may itself constitute a hazard, or the secondary (bremsstrahlung) radiation may be of importance. Data on electron flux are presented as a function of altitude and inclination in considerable detail in a NASA report,* and these data were used for determination of the interaction with potential research programs.

Bremsstrahlung radiation is the electromagnetic radiation produced by sudden retardation of high-energy electrons in nuclear electric fields. The trapped electrons in the radiation belts interact with the structure or shielding of an orbiting vehicle. Information was obtained on the variation in skin dose as a function of aluminum shield thickness from a primary electron flux and from the secondary bremsstrahlung radiation. For thicker shields, the bremsstrahlung dose rates for various electron fluxes were detailed and these data were used as necessary.

3.1.2 Screening for Manned-Space-Research Applicability

In considering the potential role of man in space research, an important factor was the condition that manned orbital research facilities be available. Thus, the monetary and engineering investments associated with providing a manned facility were not involved in assessing the relative value of manned versus automated space research. Rather, the analysis was oriented toward the operational advantages or disadvantages of the presence of man.

It was deemed reasonable to consider the incorporation of man into the facility development process, even in cases where the ultimate operational application may be completely automated (e.g., communications satellites). Problems involving the dependability or reliability of the final system could then be

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* An Analysis of the Energetic Space Radiation and Dose Rates. NASA TN D-4404, Feb. 1968.

kept separate from those of obtaining test information on system performance. Thus, in the capability development process, the man becomes a functional element, making on-the-spot decisions that contribute to the success of the overall experiment, although he need not constitute a constraint in the conversion to an operational system.

The principal benefits man brings to an orbital research program issue from his inductive capability, his adaptability, his ability to respond to unanticipated events, and other capabilities that cannot be duplicated by automation within foreseeable technology. For example, in cases where precise measurement parameters such as flux levels are not fully known in advance or dynamic ranges or scales are in error, the proximity of man to the measuring equipment permits corrective scale adjustments to be made and manual override of automated functions that might otherwise generate useless data. The beneficial contributions anticipated from manned in-orbit participation are summarized in the top headings of the matrix in Figure 3-17.

The presence of man aboard orbital research laboratories will also create some detrimental effects. For example, safety measures and special procedures to protect crew members from hazards must be included, even at the cost of additional weight, reduced usable volume, or limitation to operational performance. Similarly, the pumps, switches, and motors of the life support and environment control subsystems may produce random electrical noise affecting communication equipment operation. The involvement of man may also introduce a measure of complexity into the spaceborne experiment design. For example, it may be necessary to locate components or modules to provide accessibility, or to provide manual controls and visual displays not required for automated satellite systems.

With regard to data management, the incorporation of onboard data analysis and processing can reduce space-to-ground data link requirements but may require the training of crew members as operators and analysts.

E = ESSENTIAL
H = HELPFUL
N = NO EFFECT
T = TOLERABLE
I = INTOLERABLE
U = EFFECTS UNKNOWN

	MAN'S PARTICIPATION BENEFICIAL										MAN'S PARTICIPATION DETRIMENTAL							
	SCIENTIST/ OBSERVER				DEVELOPMENT ENGINEER				TECHNICIAN		SAFETY OF FLIGHT				MISSION PERFORMANCE DEGRADATION			
(CONTINUED FROM FIGURE 3-1)	REAL-TIME DATA-ANALYSIS AND EVALUATION	MULTIPLE SENSOR USE	SENSOR MODE AND PARAMETER SELECTION	COOPERATION WITH PRINCIPAL INVESTIGATOR ON THE GROUND	TARGET SELECTION	SENSOR OPERATION AND PARAMETER VARIATION	EVALUATION OF SENSOR DESIGN AND PERFORMANCE	COMPONENT QUALIFICATION TESTING	EQUIPMENT SETUP, CHECKOUT, MAINTENANCE, CALIBRATION, ETC.	SERVICING OF SENSOR AND EQUIPMENT CONSUMABLES	EXTERNAL ENVIRONMENT	PHYSIOLOGICAL LIMITS	PSYCHOLOGICAL STRESS	ONBOARD SAFETY	ACCELERATION DISTURBANCES	EFFLUENT RELEASE	REPETITIVE-DUTY CYCLES	CRITICAL ISSUE SUITABLE FOR MANNED SPACE FLIGHT (✓)
CRITICAL ISSUE 1	H	E	E	H	H	H	N	N	E	H	N	N	N	N	T	T	N	✓
CRITICAL ISSUE 2	N	N	N	H	H	H	E	H	H	H	N	N	N	N	N	N	N	✓
⋮																		
CRITICAL ISSUE N					(SCREENED OUT AS NON-SPACE)													

Figure 3-17. General Format of Matrix Display of Influence of Manned In-Orbit Participation on Critical Issues

Figure 3-17, considered an extension of Figure 3-1, summarizes the various aspects of manned participation considered by the study team. The three broad categories of beneficial manned participation anticipated are as a scientist/observer, as a development engineer, and as a technician. Detrimental effects of manned participation can generally be categorized under safety of flight or mission performance degradation. Because the beneficial aspects of manned participation are closely related to the nature of the individual experimental approaches, and therefore not appropriate for general discussion here, only the detrimental aspects of manned participation are discussed in the following paragraphs.

3.1.2.1 Safety of Flight

Experiment activities that may involve crew risk or cause unacceptable mental or physical duress are discussed in the following subsections.

<u>External Environment</u>

These conditions may be found in measurements that require long exposure to a radiation environment. If an unacceptable dosage is indicated, the measurement must be relegated to automated apparatus. Other examples would be extremes of temperatures or pressure.

<u>Physiological Limits</u>

These limits include such stresses as acceleration, weightlessness, physical fatigue, and dehydration, each of which may exceed the physiological tolerance of man, thereby degrading the probability of experiment success. Many of these factors are time dependent, with tolerance levels decreasing as a function of exposure times.

<u>Psychological Stress</u>

The stresses are expected to be of concern in situations involving perceptual illusions, sensory deprivation (including boredom and confinement), psychological fatigue, or extreme anxiety states.

Onboard Safety

Safety factors are exemplified by physical hazards such as sharp protuberances, high voltages, excessive noise levels (above 100 db), explosive or inflammable materials, high temperatures, or noxious, toxic or otherwise reactive materials.

3.1.2.2 Mission Performance Degradation

This category includes factors arising out of man's presence that may degrade measurements to the point of seriously compromising experiment results.

Acceleration Disturbances

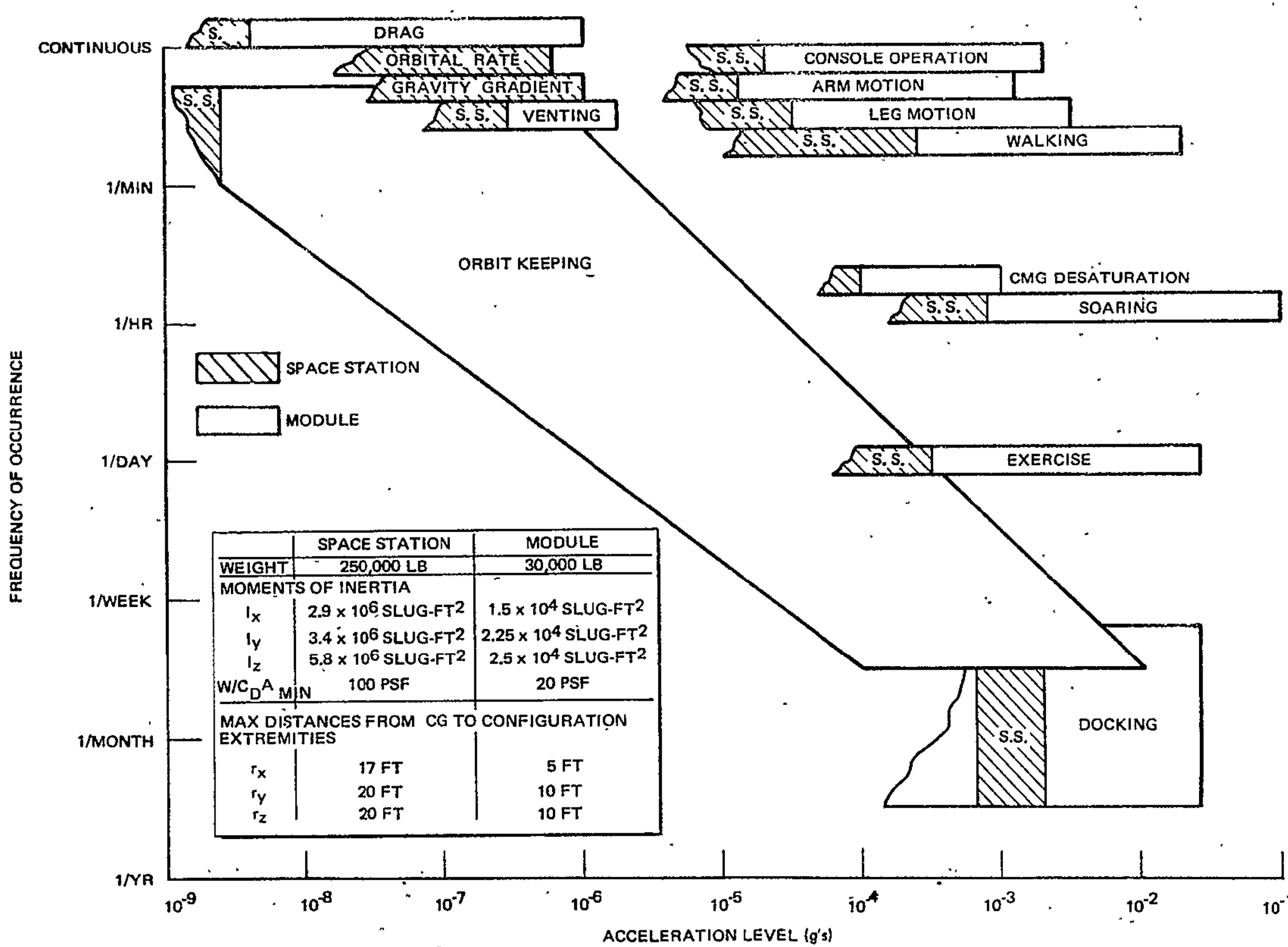
This degrading factor reflects the requirement for maintaining an extremely stable platform reference for many research activities over extended periods of time.

Figure 3-18 illustrates the disturbance accelerations imposed on a zero-g, 250,000-lb Space Station and a zero-g, 30,000-lb experiment module. The large region included in the orbit-keeping function reflects the dependence of these disturbances upon the type of propulsion system used. A resistojet, for example, would operate continuously, canceling the drag. Monopropellant or bipropellant systems used periodically to correct the orbit would impose higher levels of disturbance, probably up to 10^{-3} g.

On a near-continuous basis, accelelerations of at least 10^{-4} g can be expected because of crew movements and control activation requirements. By way of perspective, acceleration levels as high as 10^{-5} g may be unsatisfactory for specific bioscience experiments, and 10^{-3} may be unsatisfactory for most bioscience experiments. Acceleration levels less than 10^{-6} g may be required for space manufacturing activities. Thus, consideration was given in some cases to revision of the research protocols to relax the acceleration requirements.

Effluent release

The release of effluents could degrade observations, especially in the IR, visible, and UV regions of the spectrum.



	SPACE STATION	MODULE
WEIGHT	250,000 LB	30,000 LB
MOMENTS OF INERTIA		
I_x	2.9×10^6 SLUG-FT^2	1.5×10^4 SLUG-FT^2
I_y	3.4×10^6 SLUG-FT^2	2.25×10^4 SLUG-FT^2
I_z	5.8×10^6 SLUG-FT^2	2.5×10^4 SLUG-FT^2
W/C_DA MIN	100 PSF	20 PSF
MAX DISTANCES FROM CG TO CONFIGURATION EXTREMITIES		
r_x	17 FT	5 FT
r_y	20 FT	10 FT
r_z	20 FT	10 FT

Figure 3-18. Sp ıce Station Accelerations Caused by Disturbances

The estimated amount of effluents to be released during normal operation of an earth-orbiting Space Station of about 1977 technology is summarized in Tables 3-2 and 3-3; these amounts are derived from the McDonnell Douglas Phase B Space Station Study. All of the effluents listed, except propellants, would contribute to an essentially steady-state, comet-shaped cloud around the Space Station.

Although a significant proportion of the total inflight daily gas loss consists of reaction control system propellant ejection, it does not appear to cause a significant problem. The local density near the thrustors will reach the level of the normal density within 1 to 100 sec and require a clearing time of about 10 sec. With suitable placement of instrument packages with respect to thrustors, even short-period obscurations could be greatly reduced.

Most of the surrounding cloud remaining around the Space Station would be water rather than CH_4 or CO_2 because the water molecules near the Station would have a lower velocity than the other effluents. This poses perhaps the greatest problem in limiting observations because an artificial background brightness would be generated by light scattering off the ice crystals formed from the water vapor. Figure 3-19 presents the ratio of background brightness to sun surface brightness ($B/B_{\odot}$) expected at various separation distances from the Space Station for a viewing angle with respect to the sun of 60 degrees. The level of background brightness (approximately 4×10^{-13} sun-surface brightness) is reached at a separation distance of approximately 2,700 ft. For less than 100 percent conversion of water to ice crystals of approximately micron size, the relative background brightness will be reduced and the total background brightness will reach that of the natural background at a smaller separation distance. Determination of the severity of this potential problem must await *in situ* observations.

Because of the potential increase in artificial-brightness background, trash, urine, and fecal water might be stored to reduce the effluent level. Negligible light absorption and scattering in the UV are expected from the molecular contamination; however, the potential deposition of contaminants on optical

Table 3-2

TOTAL IN-FLIGHT DAILY GAS LOSSES

Daily Operations	Gas Weight (lb/day) CH_4	O_2	N_2	H_2O	CO_2	NH_3	H_2	Total
Fecal Collection	0	0.0070	0.0224	3.1203	0.0003	0	0	3.150
Trash Processing	0	0.0028	0.0028	3.0001	0.0001	0	0	3.012
Resistojet Propulsion	5.2	0	0.2	0.1 to 3.1	10.4	0	0	15.9 to 18.9
Leakage Allowance	0	0.4650	1.491	0.020	0.0240	0	0	2.0
Total								24 to 27

Table 3-3

TOTAL IN-FLIGHT EVENT GAS LOSSES

Controlled Events	Gas Weight (lb/event)							
	CH_4	O_2	N_2	H_2O	CO_2	NH_3	H_2	Total
Air Lock Operation	0	0.217	0.693	0.008	0.008	0	0	0.926
Conic Section Evacuation	0	2.29	7.30	0.08	0.08	0	0	9.75
EVA	0	1.60	0	11.0	0	0	0	12.6
Urine Recovery	0	0	0	0.385	0	0	0	0.385
Trace Contaminant Monitor	0	0.0005	0.0016	0	0	0	0	0.0021
High-thrust Propulsion								
Initial Operations	0	0	103	0	0	228	14	345
Spin/Despin	0	0	1,820	0	0	4,005	245	6,070
CMG Destruction	0	0	54	0	0	118.8	7.2	180
Docking	0	0	15.0 to 25.5	0	0	33.0 to 56.1	2.0 to 3.4	50 to 85
Maneuver Allowance*	0	0	300	0	0	660	40	1,000
Total								7,645 to 7,680

*Continuing allowance, not required on initial allowance.

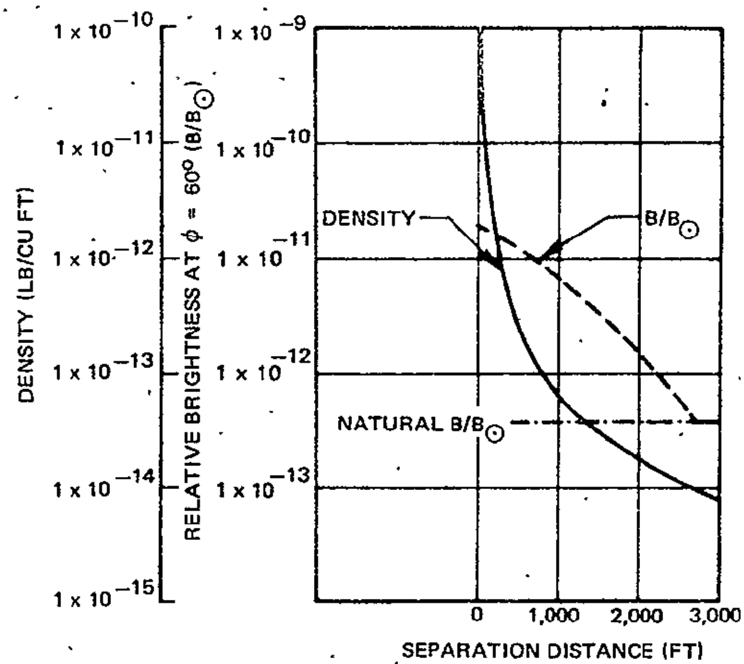


Figure 3-19. Density and Relative Brightness Effects as a Function of Separation Distance From Space Station

surfaces should be minimized. Therefore, any easily attained modifications to the vehicle design that would reduce the effluents should be made. It should be emphasized that the magnitude of the effluent problem is hardware dependent. Proper vehicular design could significantly aid in solving this potential problem.

Repetitive Duty Cycles

If an experiment should require continuous or repetitive observations to be made with great precision, the performance of the human observer would become unreliable. Not only is the observer limited in terms of motor speed and accuracy (5 to 14 discrete actions/sec), but high rates of psychomotor performance can only be maintained for short periods of time (minutes rather than hours). The variability and basic individual differences in performance capabilities of human observers, are additional disadvantages in using man directly in the prime control loop of any laboratory procedure that requires precise actions or observations on a repetitive basis over an extended period of time.

3.1.3 Contributions of Ongoing Programs

In addition to screening for space versus nonspace and manned versus automated applicability, the study team examined past, present, and new (funded) programs for their relevance to the critical issues developed in the organized overview. Thus, those critical issues that have been or are being satisfied by present programs were eliminated from further consideration. The task of identifying a broad array of present and past programs and determining their relevance to the critical issues was complicated because some programs are classified, as in Communications and Navigation. In other categories, e.g., Space Biology, a large number of small funded studies that are relevant at least in part had to be surveyed.

Most of the present large NASA programs are summarized in the "Hearings Before the Subcommittee on Space Sciences and Applications." Various present NASA programs are summarized in sufficient detail to evaluate their relevance to specific groups of critical issues. Another source of information was the descriptions of the planned Skylab A experiments.

It became apparent in the course of this investigation that each of the six study disciplines had to be treated in an individual manner. In some disciplines, hardly any ongoing programs exist, while in others an abundance of previous knowledge through space experiments is available. In this situation, it is difficult to provide any generally applicable description of the procedures followed. An example is shown, however, for Space Physics, in Table 3-4.

Essentially, this table compares the specific objectives of known programs with applicable critical issues; the degree of correlation is graded according to rules annotated to the table. This grading procedure is based on two somewhat independent parameters: (1) the overlap of the goals and objectives of the known program with the critical issues and (2) the expected contribution

Table 3-4 (Page 1 of 3)

CONTRIBUTIONS TO SOME SPACE PHYSICS CRITICAL ISSUES FROM ONGOING PROGRAMS

Program	Broad Objectives	Measurements Related to Critical Issues	Critical Issues Involved	Corre-lation*	Remarks
Sounding Rockets	Study of upper atmosphere at altitudes between 80 and 1,000 miles	Composition of atmosphere and ionosphere, energetic particles, electron temperature, density, etc.	4.2.1.2.1.3.3 4.2.1.2.1.3.4 4.2.1.2.1.3.5	2B	Can only make short-duration spot surveys
OGO OGO-F	Study of Earth environment and interplanetary space. Correlation of geophysical phenomena with solar radiations. Sun-Earth relationships	Structure of magnetosphere, atmospheric composition, airglow and auroral phenomena	4.2.1.2.1.3.5	3C	Program objectives can only be partially achieved by unmanned satellites. Simultaneous data at different locations would be desirable.
Physics Explorers IMP-E Solrad-B IMP-G, I, H, J SSS-A, B ISIS-A, B, C INJUN RAE-A SAS	Exploration of Earth environment, sun-Earth relationships, nature of interplanetary medium	Information on Earth's magnetosphere and magnetic tail. Air density, very low-frequency radio waves. Ionosphere at high latitudes	4.1.6.4.3.2.3 4.1.6.4.3.2.4 4.1.6.4.3.3.1 4.2.1.2.1.3.4 4.2.1.2.1.3.5	3C	Program objectives can only be partially achieved by unmanned Explorer-type probes

Table 3-4 (Page 2 of 3)

CONTRIBUTIONS TO SOME SPACE PHYSICS CRITICAL ISSUES FROM ONGOING PROGRAMS (Continued)

Program	Broad Objectives	Measurements Related to Critical Issues	Critical Issues Involved	Correlation*	Remarks
Pioneer VI VII VIII IX E F G	Continuous study of interplanetary medium and propagation of solar and galactic radiation. Exploration of remote regions of solar system. Dynamic phenomena that shape the Earth's environment. Particle and field characteristics during solar cycle	Solar wind characteristics, magnetic fields, electron density in space, energy spectra, fluxes and direction of solar and galactic cosmic rays. Hazardous region of asteroid belts, charged particles of radio frequency emission. Magnetically clean probes for study of energy spectra and particle and field distributions	4.2.1.2.1.3.4 4.2.1.2.1.3.5 4.2.1.3.2.3	4B, 3B	Interplanetary missions can be achieved by small unammed satellites
Skylab A	Materials Processing (expmt M512)	Metals melting and welding	Clusters** 4-P/C-6, -8	2C	Do not provide full coverage of critical issues, but do provide valuable design criteria with respect to the dependent variables related to near-zero-gravity processing, such as surface tension and interfacial tension effects, geometrical tolerances, etc.
		Exothermal heating (tube brazing)	Clusters 4-P/C-6, -8	2C	
		Spherical forming	Clusters 4-P/C-6, -7	2C	
		Composite casting	Cluster 4-P/C-2	2C	
		Single crystal growth	Cluster 4-P/C-6	2C	

Table 3-4 (Page 3 of 3)

CONTRIBUTIONS TO SOME SPACE PHYSICS CRITICAL ISSUES FROM ONGOING PROGRAMS (Continued)

Program	Broad Objectives	Measurements Related to Critical Issues	Critical Issues Involved	Correlation*	Remarks
Skylab A (Cont)	Flammability tests (expmt M479)	Flame propagation, surface and bulk flame propagation rates, self-extinguishment, extinguishment by vacuum or water spray	Cluster 4-P/C-1	2C	Experimental coverage and information obtained not sufficient to relate to required fundamental data, but will provide some experimental design criteria

*Correlation Code

Scope of Objectives

0 = No apparent correlation with critical issues

1 = Poor correlation with critical issues or correlation in some details

2 = Partial overlap with critical issues

3 = Coverage of major portion of critical issues

4 = Identical in scope with critical issues

Comparison of Information Gain

A = Information gain will fulfill needs of critical issues

B = Information gain could possibly fulfill needs of critical issues

C = Information gain insufficient to fulfill needs of critical issues

**Critical issues addressed in the clusters are identified in Appendix C.

of the known programs to resolving specific critical issues.

The impact of ongoing programs on each of the disciplines is discussed in the following subsections.

3.1.3.1 Manned Space Flight Capability

Of the 857 critical issues remaining after screening for space and manned space applicability, 72 were eliminated on the basis of anticipated accomplishment by the Skylab A program. An additional 90 critical issues were identified as having their measurement requirements satisfied by Integrated Medical and Behavioral Laboratory Measurement System (IMBLMS). However these 90 are included in the Research Cluster Descriptions.

3.1.3.2 Space Biology

Biology was found to be unique among the scientific and technical disciplines investigated in the study in terms of the universal applicability and controlled environmental differences to gaining understanding and knowledge in the discipline. The recommendations for Space Research made by the American Institute of Biological Sciences provided guidance to the study team in reviewing over 180 NASA-supported ground-based and unmanned satellite research programs in biology to determine their contribution toward solving the critical issues identified during the study. Upon analysis, it was concluded that the entire field of biology is appropriate for continued investigation in zero gravity because it covers the fundamental relationships of living organisms and their environment. Even the investigations conducted to date in the Biosatellite program require replication in future missions. Consequently, none of the critical issues were dropped because of the information gain expected from present programs.

3.1.3.3 Space Astronomy

Present programs are divided into three groups.

A. <u>Earth-orbital missions</u> Unmanned programs include (1) the Orbital Astronomical Observatory (OAO) and the Orbital Solar Observatory (OSO) to study spectral regions invisible from earth, (2) the

Radio Astronomy Explorers that measure radio signals from celestial sources in the 0.1 to 10-MHz range, and (3) the Small Astronomy Satellite that will detect xrays and gamma rays from galactic and solar system sources. The Apollo Telescope Mount experiments to be flown on Skylab A are examples of manned Earth orbital missions supporting above-the-atmosphere solar phenomenon observations.

B. Suborbital missions These missions include (1) rocket and high-altitude balloon projects and (2) high-altitude aircraft missions to observe solar eclipse phenomena and carry out programs of infrared astronomy.

C. Interplanetary probes or in situ missions Past and current probes include (1) the Mars and Venus Mariner flybys, (2) the Pioneer missions, and (3) the soft-Mars-Landing Viking program aiming at a mid-1970's mission.

It is anticipated that during the next decade significant progress can be made by present and planned space astronomy programs toward answering a variety of critical issues in whole or in part. However, because it is uncertain which of the planned programs will eventually be carried out, all of the critical issues were retained.

3.1.3.4 Space Physics

In the subdiscipline of relativity and gravitation, some of the critical issues would have been screened out on the basis of the present programs except that they were previously screened out on the basis of automated or non-earth-orbital spacecraft being preferred to earth-orbital manned research facilities. This potential for screening out can be partially attributed to interplanetary probes recently launched. This includes the Mariner VI and VII launches that are equipped with radar transponders, making it possible to determine certain relativistic effects with greater precision than possible from a manned orbital space facility. In one area, concerned with the detection and analysis of gravity waves, the critical issues were previously screened out on the basis of existing and planned ground-based programs with the promise of being more productive for the foreseeable future than any space-based research.

Unmanned spacecraft that supported the subdiscipline of Plasma Physics include (1) the International Satellite for Ionospheric Studies (ISIS) that measures electron and ion density and temperature, (2) the Orbiting Geophysical Observatory (OGO) series that studies particle activity, aurora and air glow, and geomagnetic fields, and (3) the Small Scientific Satellite (SSS-A and -B) series, in which each launch provides a vehicle carrying an integrated set of sensors for a group of experiments with common objectives. However, none of these programs are sufficiently complete to warrant the elimination of any critical issues. In summary, no critical issues in Space Physics were eliminated specifically because of ongoing programs.

3.1.3.5 Communications and Navigation

In screening the space-oriented critical issues, a comprehensive evaluation of present Government and commercial research programs was not undertaken mainly because of the security aspects and general lack of published unclassified data accessible to the study team. Principal guidance was obtained from available NASA documents.

It was appropriate to eliminate 14 critical issues on the basis of the contributions of present programs to their resolution. These issues were identified in the study primarily because they point to future component and subsystem development requirements. They are related to current applications involving planetary missions, Apollo operations and support requirements, and OSSA automated satellites.

Several of NASA's active programs provided valuable information which will contribute to the resolution of some of the critical issues identified for manned space research. Examples are (1) the ATS-F automated satellite using a 30-foot parabolic antenna for demonstration of TV broadcasting to communities in India and (2) the ATS-1 satellite, to be used for initial space link demonstrations of the distribution of medical information between Maryland and

Alaska.

3.1.3.6 Earth Observations

A number of automated spacecraft are providing supportive data derived from observations of the earth from orbit. The TIROS Operational Satellites (TOS) and the R&D NIMBUS program are providing valuable meteorological data and have given the scientific community new insights into global weather phenomena. The synchronous orbiting ATS-1 and ATS-3 using the spin scan camera system have provided synoptic high-resolution cloud cover mapping which led to the development of new theories on atmospheric interactions between the northern and southern hemispheres.

The planned Earth Resources Technology Satellite (ERTS) can be expected to support a wide variety of remote sensing research in agriculture, hydrology, geology and geography, especially in consort with aircraft flight testing of sensors over ground truth sites. The unmanned geodetic active (GEOS) and passive (PAGEOS) satellites with complementary ground instrumentation have improved the accuracy of measurements of the earth's gravitational field by two orders of magnitude. Future so-called drag-free satellites in this series are specific examples of automated spacecraft addressing earth physics critical issues not well suited for manned orbital research facilities.

The overall conclusion drawn from examination of present programs in Earth Observations is that a preponderance of the remote sensing research activities are at a very early stage of development and are addressed primarily to contributions that could be made by automated rather than by manned facilities. Therefore, critical issues were not in general eliminated because of anticipated accomplishments of present programs.

In general, the influence of present programs on the screening of critical issues was slight. The only significant block of issues rejected (some 72) was caused by the influence of the Skylab A program on the Manned Space Flight Capabilities discipline. Approximately 14 critical issues in the Communications and Navigation discipline were screened out because they were related to current programs and were identified in the study only because of their value in pointing to supporting technology development requirements.

3.2 SCREENING AND GROUPING OF CRITICAL ISSUES IN MANNED SPACE FLIGHT CAPABILITY

The 1,468 issues generated in the organized overview analysis were subjected to the screening process described in Subsection 3.1. The 785 critical issues remaining after screening were grouped into 42 research clusters. Details of this process are described in the following subsections.

3.2.1 Screening for Space-Research Applicability

The space-nonspace filter, addressed to each remaining issue the question, "Must it be done in space or can it be done on the ground?"

3.2.1.1 Space Criteria Peculiar to Manned Space Flight Capability

Rejection of research items that could obviously be satisfied in ground based research, facilitated the identification of critical issues for Manned Space Flight Capability. The criticality of the space-spacecraft environment and its affect upon the systems of interest is emphasized.

Long term weightlessness cannot be provided in earth-bound research to test the validity of the various simulation techniques used in biomedical research. There are many differences between these simulations and true weightlessness. It is necessary to use space flight to study accurately the biological effects of weightlessness.

Some physiological functions are dependent upon the movement of materials along electrochemical gradients that hypothetically would be relatively unaffected in the weightless environment. Neural transmission functions are in this category. Other structures and functions, i.e. reproduction, are not of immediate importance in biomedical aspects of space flight. Critical issues on functions like these were only identified. These issues were rejected for space research for the immediate future. Two groups of issues in this group are described below.

A. Nerve Impulse Transmission—Critical issues concerned with nerve impulse transmission are not considered reasonable candidates for space experiment, inasmuch as no indication of gravitational effects has been noted in terrestrial research. The included critical issues are:

(1.1.1.1.3.2.1) Resting Potential
(1.1.1.1.3.2.2) Threshold Changes
(1.1.1.1.3.2.3) Nerve Impulse Characteristics
(1.1.1.1.3.2.4) Synaptic Transmission
(1.1.1.1.3.2.5) Chronaxie Changes

B. Reproductive Function—Since planet colonization or space flights of a duration greater than the life span of the originating astronauts are not within the scope of the present study, reproductive function as a biomedical entity will not be considered for further analysis, although it may be a valid area for Space Biology. The critical issues terminated in this area are:

(1.1.1.1.9.1) Spermatogenesis, Oogenesis, and Ovulatory Function
(1.1.1.1.9.2) Copulation and Fertilization
(1.1.1.1.9.3) Fetal Development
(1.1.1.1.9.4) Parturition

From the standpoint of psychological research in space the major stress, with the possible exception of weightlessness, is the fact that the flight crew is exposed to real hazards from which they cannot readily remove themselves. No matter how realistically planned, ground-based research is not completely capable of simulating this effect.

Qualification of man in performance of a variety of extravehicular tasks is one of the important goals of manned space flight. Experience to date with ground-based simulations has been that such simulations help the astronaut in actual space flight performance, but performance under actual space conditions is more difficult than in ground simulation.

The physical processes involved in hardware in the Life Support and Protective Systems and in Engineering Experiments (including fluid and gas interfaces, heat transfer, phase changes, and material transport processes) are extremely susceptible to the weightless environment of space. No real capability exists for simulating this environment in ground-based research.

Operations Experiments involve crew members, operational equipment, and procedures. Critical issues in this area require evaluative measurements of each of these factors. Since man is involved in all of these operations, the same criteria that apply to Biomedical and Behavioral critical issues apply to Operations issues.

Critical issues were not evaluated (or rejected) on the basis of cost or scientific worth, state of the measurement art, ability of the spacecraft to accommodate them, crew workload, or other technical factors. All of these considerations are important and their reevaluation at a time when complete experiment descriptions are available is a valid basis for future study efforts.

For each of the subdisciplines of Manned Space Flight Capability, Table 3-5 summarizes the numbers of critical issues initially identified, the number screened out for several types of reasons, including lack of space-research applicability, and the number remaining after screening.

3.2.2 Screening for Manned-Space-Research Applicability

The issues surviving the space-nonspace screening were screened to elminate those issues which, though they required experimentation in space, would be more advantageously answered using automated (unmanned) platforms.

The main criterion for this step is the need for man. Obviously, if man is the object being observed or measured, he is needed. He may also be needed because the object being measured must be manipulated or operated directly by man. Relative need is also included in this criterion. In some cases man's presence may not be mandatory but may be highly desirable. In these cases, acceptance or rejection of the critical issue may well depend on the two criteria discussed in the next two paragraphs.

Another criterion used in this phase is concerned with the degradation of the observation or measurement by man's presence. His presence on the vehicle might degrade measurements by reason of the disturbance torques that he imparts to the spacecraft by his movement or by the contaminants that he produces. On the other hand, the equipment required to support man's presence may degrade measurement by (1) the acoustic and acceleration forces produced, (2) the environment (atmospheric, pressure, lighting) that it supplies to support man, or (3) the contaminants produced.

A final criterion of interest is safety. If there are hazards having a high probability of occurrence and causing death or injury to crewmen, then if possible, the critical issue must be answered by use of an automated space platform. To quality for implementation in a manned vehicle, each critical issue must pass these two criteria.

In Biomedicine and Man-System Integration, the issues remaining at this point involve experiments on man himself, or animal experiments that appear to benefit from the attendance of man. Consequently, no critical issues could be terminated on the basis of the manned-versus-automated filter, since they meet the first criterion above.

Life Support and Protective Systems issues were examined using the need-for-man criterion, and all issues identified in Appendix B were judged to require manned space experimentation.

All Operations Experiments critical issues require the presence of man, since he is one of the three elements being evaluated (the other two are the operational equipment and the operational procedures). No issues in this category were rejected, they are considered critical.

In Engineering Experiments, all critical issues require the presence of man because they deal with the interface between man and the subsystems of the space vehicle. Therefore, none of the critical issues was rejected.

Table 3-5

SUMMARY OF SCREENING OF CRITICAL ISSUES IN MANNED SPACEFLIGHT CAPABILITY

	Subdiscipline	Critical Issues From Table 1, Appendix B	Critical Issues Eliminated by Preliminary Screening (PS)*	Critical Issues Screened Out as Non-Earth-Orbital Research Candidates (NS)*	Critical Issues Screened Out as Automated (Unmanned) Research Candidates (UM)*	Critical Issues Screened Out Due to Accomplishments of Ongoing Programs (OP)*	Critical Issues Deferred Due to Requirements for Advanced Experimental Concepts (AC)*	Critical Issues Principally Concerned With Another Discipline (SB, SA, SP, CN, or EO)*	Critical Issues Assigned to Research Clusters (1-AB-YY)*
(1.1.1)	Biomedicine	274	10	0	0	0	44	11	209
(1.1.2.1)	Behavioral Research	328	103	84	0	0	4	0	137
(1.1.2.2)	Man-Machine Research	75	9	0	0	0	0	0	66
(1.1.3)	Life Support and Protective Systems	201	0	0	0	0	0	0	201
(1.2)	Engineering Experiments	505	206	95	0	72	31	0	101
(1.3)	Operations Experiments	85	2	8	0	0	2	2	71
	TOTALS	1,468	330	187	0	72	81	13	785

*Marginal coding used in Table 1, Appendix B.

In summary, all of the critical issues retained after application of the space--nonspace screening also passed the manned-automated screening, as indicated in Table 3-5.

3.2.3 Contributions of Ongoing Programs

3.2.3.1 Ongoing Programs Considered

A large number of NASA-sponsored programs are related to space experiments and to the development of inflight measurement techniques. Only one, however, has a firm commitment for future space operations, the experimental program for Skylab A. Critical issues associated with Skylab A experiments are considered to be satisfied and were not included in the Research Cluster Descriptions.

Programs concerned with instrumentation development, such as the proposed integrated medical and behavioral laboratory measurement system (IMBLMS), 1 not define the experimental programs to satisfy the information requirements. Critical issues were therefore not eliminated in the screening-and-grouping process described here but were retained for inclusion in the earth-orbital research program.

3.2.3.2 Anticipated Accomplishments of Ongoing Programs

In general, the accomplishments expected from Skylab A that are applicable to Manned Space Flight Capability fall into the following five areas:

1. Evaluation of specific Skylab habitability features with crews of three for periods up to 56 days.
2. Evaluation of operational subsystem performance and man's capabilities in interfacing with the subsystems for periods up to 56 days.
3. Evaluation of astronaut mobility and work capability (both IVA and EVA) for periods up to 56 days.
4. Selected medical and biological data to evaluate the effects of weightlessness and other space environment characteristics on man for periods up to 56 days.
5. Engineering and technological data applicable to the development of advanced space vehicles and experiments.

Listed below are the presently approved Skylab A experiments applicable to Manned Space Flight Capability and the anticipated information requirements that will be satisfied by successful performance:

1. D021 Expandable Airlock Technology.
   A. Astronaut EVA ingress-egress capability.
   B. Design data on deployment of this type of device for manned vehicles
2. D024 Thermal Control Coatings.
   A. Assessment of effects of surface coatings on passive thermal control systems.
   B. Heat sink effectiveness of space radiators.
   C. Astronaut EVA capability in retrieving samples.
3. M071/M073 Mineral Balance and Bioassay of Body Fluids.
   A. Calcium, phosphorus, and magnesium balance.
   B. Electrolyte balance.
   C. Nitrogen balance and associated measurements.
   D. Stress hormone release levels.
   E. Astronaut capability in performing biomedical tasks in space.
4. M072 Bone Densitometry.
   A. Density of bones (preflight and post-flight).
5. M074 Specimen Mass Measurement.
   A. Masses of biological samples.
   B. Astronaut capability in calibrating mass measurement devices.
6. M092 Lower Body Negative Pressure (preflight, in-flight, and post-flight).
   A. Orthostatic tolerance.
7. M093 Vectorcardiogram.
   A. Electrical activity of heart.
   B. Electrical axis of the heart.
   C. Astronaut capability in collecting scientific data.
8. M111 Cytogenic Studies of Blood (preflight and post-flight).
   A. Red blood cell morphology.
   B. White blood cell morphology.

9. M112 Immunology Study (preflight and post-flight).

   A. Immunological profile of crew.

10. M113 Blood Volume and Red Cell Life Span.

   A. Plasma volume.

   B. Red cell mass.

   C. RBC production rate.

   D. Red cell life span.

   E. Red cell sequestration.

11. M114 Red Blood Cell Metabolism.

   A. O_2 consumption and CO_2 production of RBC.

12. M131 Human Vestibular Function.

   A. Agravic Perception.

   B. Ocular counterrolling.

   C. Oculogyral illusion.

   D. Angular acceleration threshold.

   E. Motion sickness susceptibility.

   F. Astronaut capability in performing experimental functions.

13. M151 Time and Motion Study.

   A. Evaluation of motion picture technique for performance assessment.

   B. Light levels required for motion picture coverage under various conditions.

14. M171 Metabolic Activity.

   A. O_2 consumption and CO_2 production.

   B. Respiratory rate and minute volume.

   C. Blood pressure.

   D. Body temperature.

   E. Metabolic data on suited and unsuited astronauts performing maintenance tasks.

15. M172 Body Mass Measurement.

   A. Body weight.

   B. Crewman capabilities to calibrate and use body mass measurement device.

16. M487 Habitability and Crew Quarters.

    A. Baseline habitability design data for future space platforms (waste management, water management, personal hygiene, food, sleep restraints, and other habitability provisions).

    B. Evaluation of techniques for measuring effectiveness of habitability provisions.

17. M507 Gravity Substitute Workbench.

    A. Astronaut capability to perform maintenance activity using aerodynamic and electrostatic forces as gravity substitutes.

    B. Design data for maintenance worksites.

18. M508 Astronaut EVA Hardware Evaluation.

    A. EVA suit, umbilical, and backpack characteristics.

    B. Evaluation of astronaut EVA capability to perform precise hand movement tasks, two-hand fine manipulative tasks, gross and precise force and torque application tasks, and operational maintenance tasks.

    C. Data on effectiveness of techniques for assessment of EVA performance.

19. M509 Astronaut Maneuvering Equipment.

    A. Preparation of design data for future astronaut maneuvering equipment.

    B. Evaluation of present state-of-the-art maneuvering concepts (direct jet, rate-gyro/jet, CMG units, and hand-held maneuvering units).

    C. Evaluation of data on effectiveness of ground simulations for astronaut maneuvering tasks.

20. M512 Material Processing in Space.

    A. Astronaut capability to perform electron beam welding, brazing, and casting in space.

21. S015 Zero-Gravity Investigation of Single Human Cells.

    A. Astronaut capability to make visual observations in space.

    B. Astronaut capability to perform experimental operations in space.

22. S019 Ultraviolet Stellar Astronomy (also S020, S052, S063, and S101).

    A. Astronaut capability to perform experimental photographic observations in space.

23. S054 X-Ray Spectrographic Telescope (also S055A, S056, S082A and S082B).
    A. Astronaut capability in space for visual observations and use of the Apollo Telescope Mount (ATM) for filming of sun.
24. T013 Crew and Vehicle Disturbances.
    A. Effects of various crew motions on spacecraft dynamics.
25. T020 Foot-Controlled Maneuvering Unit.
    A. Preparation of design data for advanced maneuvering equipment.
    B. Evaluation of astronaut capability in maneuvering (suited and unsuited).

Table 3-5 indicates that 72 critical issues were screened out as a result of the above activities.

3.2.4 Critical Issues Requiring Advanced Concepts

Eighty-one issues were deferred due to requirements for advanced experimental concepts, as indicated in Table 3-5. In some cases, it was not considered feasible to define experiments to answer the critical issues because anticipated state-of-the-art concept and hardware development are in the distant future. In other cases, experimentation was rejected due to severe problems of crew safety. Finally, experiments for some critical issues were not defined because space research conditions favorable to such experimentation will not be available in the foreseeable future.

In the Biomedicine subdiscipline, items of interest deferred for this reason included those concerned with drug administration, drug action, and medical care for traumatic injuries such as cold injury, lung trauma, and eye injuries. It was felt that advanced concepts of experimentation guaranteeing crew safety must be developed before specific methods of manned experimentation in this area can be defined. Some of the Behavioral Research issues dealing with depth perception were deferred because to answer them would involve measurement of visual processes in free space outside the space vehicle, and concepts for this type of experimentation have not been developed.

A number of Engineering Experiments issues were deferred due to a lack of hardware concepts amenable to experimentation. These included, in Data Management, questions regarding light beams as transmission systems for data; in Electrical Power, questions regarding nuclear reactors as heat sources; and in Stabilization and Control, the use of radio-isotope thrusters and subliming solid thrusters for propulsion.

Operations Experiment issues associated with ejectable data capsules were deferred because it was not anticipated that this type of space-to-ground data return technique will be used operationally in the foreseeable future.

3.2.5 Grouping of Critical Issues into Research Clusters

The issues remaining after the screenings are considered to be critical. These were grouped into research clusters according to similarities of experimental techniques or approaches in which the maximum number of critical issues could be satisfied by the minimum number of measurement techniques and instruments. Forty-two research clusters were identified within the five research areas previously discussed and are listed below.

Biomedicine

Cluster No.	Title
1-BM-4*	Effects of Weightlessness on Circulatory Function
1-BM-5	Radiation, Toxicology, and Medical Problems
1-BM-6	Effects of Weightlessness on Stress Response
1-BM-7	Effects of Weightlessness on the Nervous System
1-BM-8	Effects of Weightlessness on Gastrointestinal Function
1-BM-10	Body Fluid Analysis
1-BM-12	Studies on Instrumented Animals
1-BM-13	Effects of Weightlessness on Pulmonary Function
1-BM-14	Effects of Weightlessness on Metabolism
1-BM-15	Centrifuge Studies

* Missing numbers were assigned to clusters that were later combined with others or eliminated.

Man-System Integration (including Behavioral Research and Man-Medicine Research)

1-BR-1	Sensory, Psychomotor, and Cognitive Behavior (5 parts)
1-BR-2	Group Dynamics and Personal Adjustment
1-BR-3	Complex Task Behavior
1-BR-4	Skills Retention
1-BR-6	Performance Measurement
1-MM-1	Controls and Displays
1-MM-2	Locomotion and Restraint
1-MM-3	Habitability
1-MM-4	Work/Rest/Sleep Cycles
1-MM-5	Performance Aids

Life Support and Protective Systems

Cluster No.	Title
1-LS-1	Phase Change and Thermal Processes
1-LS-2	Material Transport Processes
1-LS-3	Atmosphere Supply Processes
1-LS-4	Water Management
1-LS-5	Water Electrolysis
1-LS-6	Food Management and Processes
1-LS-7	Atmosphere Purification Methods
1-LS-8	Life Support Monitoring and Control
1-LS-9	Waste Management
1-LS-10	Heat Transport Equipment
1-LS-11	Crew Equipment and Protective Systems
1-LS-12	Life Support System Maintenance and Repair

Engineering Experiments

1-EE-1	Data Management
1-EE-2	Structures
1-EE-3	Stabilization and Control (3 parts)
1-EE-4	Navigation and Guidance (4 parts)
1-EE-5	Communications

Operations Experiments

1-OE-1	Logistics and Resupply (2 parts)
1-OE-2	Maintenance, Repair, and Retrofit
1-OE-3	Assembly and Deployment
1-OE-4	Module Operations
1-OE-5	Vehicle Support Operations

3.2.6 Alternative Experimental Approaches in Manned Space Flight Capability

Alternative measurement methods were considered for obtaining the information required for critical issue resolution. The primary criterion of selection was the effectiveness of the measurement technique in terms of accuracy, precision, and reliability. Additional criteria considered included measurement state of the art; commonality of the measurement technique in answering multiple critical issues; influence on spacecraft in terms of weight, volume, and power; and crew time requirements. For the most part, in the Manned Space Flight Capability discipline, there were few reasonable alternatives to the measurement techniques selected. Those that were considered are discussed in the following subsections.

3.2.6.1 Biomedicine Experimental Approach Alternatives

In many instances, the critical issues resulting from the analysis concerned functions of discrete portions of larger, more complex systems. It was decided that the general, gross functioning of the systems would be studied first, after which the individual aspects would be investigated as required. Included in the latter category would be those aspects of biological systems that remain unaffected by weightlessness. Examples include a determination of changes in total plasma fractions, a general assessment of digestive and absorptive functions by means of test meals, and fecal analyses prior to an investigation of the activity of discrete gastrointestinal secretions.

3.2.6.2 Behavioral Research Measurement Techniques

In the Behavioral Research segment of the Man-System Integration subdiscipline, a substantial number of individual behavioral measurements can be accommodated by the IMBLMS. No reasonable measurement alternatives exist for the IMBLMS provisions for sensory, psychomotor, and problem-solving measurements.

For complex task performance and group behavior, a TV technique supplemented by audio measurement and recording devices is the preferred method. Whether or not to use real-time coverage (on the order of 30 frames per second) as opposed to time-lapse methods (one frame every 2 or 3 seconds) is a question to be resolved. Alternative techniques considered include motion pictures, paper-and-pen questionnaires, and projective tests. All of these techniques suffer from time delays in availability of data and from the imposition of added crew time for implementation. It is recognized that dependence on TV techniques implies confidence that ground testing with such devices in the next few years will result in the development of valid and reliable techniques for extracting the required data from TV and audio records.

3.2.6.3 Man-Machine Research Measurement Techniques

Basic to the selection of measurements techniques for the Man-Machine Research segment is the context within which measurements will be made. Research segment is the context within which measurements will be made. The experimental approach involves observation and measurement of normal mission and experimental crew activities. The parameters of interest include task times and error scores, crew subjective reactions to hardware accommodations, and the frequency and magnitude of the use of facilities. Measurement techniques selected must impose little or no crew workload and not intrude upon the crew to the extent that they affect the behavior being measured. A combination of TV and audio coverage and automatic sensors to detect the frequency of facility use is the preferred method for measurement of these activities. Supplementing these direct measurements will be selected physiological parameter measurements for correlation with performance and behavioral states. The alternative examined in this area was the use of the traditional technique of subjective questionnaires (such as habitability questionnaires). Such questionnaires may be used in early flights as criterion measures or for verification of data acquired by more advanced tehcniques.

3.2.6.4 Life Support and Protective System Measurement Techniques

Measurement requirements identified in Life Support and Protective Systems were found to be those dealing with specific physical conditions of fluids and equipment used in various research clusters. The most common measurement requirements include temperature, pressure, humidity, flow rate, mass, density, and surface tension of fluid at specific locations in equipment tested. Also included are chemical, biological potability, and gas analyses of processed fluids and current, voltage, heat flux, and acceleration levels of the test equipment. For most of the measurement requirements listed, it was possible to recognize and adopt a generally accepted approach. In only two cases did alternative approaches have to be considered:

1. Potability analysis may utilize either the chemical oxygen demand (COD) or total organic carbon (TOC) approach. The TOC method measures essentially all of the carbon available in a given sample. It will be used because it is believed to be a more accurate, as well as a more rapid, approach than the standard COD method.
2. Gas analyses may be made by either gas chromatography or mass spectrometry. Through gas chromatography, it is possible to identify gases that have been anticipated in advance, whereas mass spectrometry produces precise, qualitative identifications of any species found in the sample. Both of these techniques are recommended for use.

Instrumentation for these selected techniques of both potability and gas analysis has yet to be developed in flight-type designs.

3.2.6.5 <u>Engineering Experiment Measurement Techniques</u>

The philosophy within which Engineering Experiment critical issues were generated is that selected system elements or components will be flown in manned spacecraft as specific experiments and not as parts of the spacecraft's operational subsystems. Physical measurements required for the assessment of equipment performance include temperature, pressure, power, and fluid flow, and represent techniques with which considerable space experience has been accumulated. For these measurements, the selected approach was one widely used and accepted.

For those critical issues related to man's capability in performing the necessary interface with specific hardware, the experimental approach selected is the same as that for man-machine research, i.e., observation by means of video techniques. This technique is supplemented, however, by subjective reports by the crewmen involved.

3.2.6.6 Operations Experiment Measurement Techniques

Basically, two types of measurements are required to answer Operations Experiment critical issues: human performance measures and equipment state measurements. Equipment state measurements generally fall into the same categories as Engineering Experiments and offer little in the way of reasonable alternative techniques. Equipment operations such as deployment, however, are amenable to direct observation and should be monitored by photography or TV. Instrumentation of the equipment for measurement of this type of parameter was rejected as being more complex than necessary for the information required by the critical issues.

For the human performance measures required in Operations Experiments, time-lapse video (augmented with crew comments) can provide the required time and error data, along with additional information on any unusual difficulties encountered. The alternatives considered and rejected included use of another crewman as a direct observer and use of motion picture techniques. Use of crewman observer requires additional crew time and cannot provide as objective a record as is available from a TV record. Motion picture film, though comparable in objectivity to TV, does not permit the flexibility in real- or near-real-time evaluation of the operation being examined.

3.2.7 <u>Brief Descriptions of the Research Clusters</u>

In summary, in the study discipline of Manned Space Flight Capability, 42 research clusters were formed from the 785 critical issues judged to be suitable for a manned earth-orbital research program. Brief descriptions of the research clusters for each subdiscipline are presented below. Detailed descriptions of each of the research clusters may be found in Appendix C.

SUBDISCIPLINE SYNOPSIS

1-BM

Biomedicine

1. Research Objectives

The biomedical research program, which is directed toward the definition and solution of problems concerning the optimum utilization of man in advanced space systems, has as its objective:

> "To determine the adaptiveness and tolerance of man to space operations, including the basic understanding of the fundamental mechanisms involved; to define the progression of physiological alterations in man for predictive applications; to assess his potential to function effectively in non-terrestrial environments; and to assure the functional integrity of man through the provisions of appropriate protective and/or therapeutic measures."

In order to define a research program responsive to the broad objective, the following three subobjectives, were derived.

1. Physiological Changes-considers all potential adaptive changes in the physiological systems resulting from prolonged exposure to weightlessness.
2. Medical Problems-considers changes of a medical nature including changes in susceptibility to illness or injury, changes in the healing process, and changes in therapeutic or preventative techniques resulting directly from exposure to weightlessness or secondarily from initial physiological changes.
3. Stress Tolerance Changes-considers alterations in physiological compensatory reactions to environmental stresses which may result in the definition of new safety levels for environmental parameters or changes in our present concepts of their optimum values.

Each of the three subobjectives was expanded further. "Physiological Changes" was examined with respect to the various physiological functions. Nine divisions were made which could include all potential physiological changes.

Five subordinate categories were considered sufficient to contain all of the various space-related Medical Problems. These were; response to medication, microbial infections, traumatic injuries, diagnostic signs, and preventative treatments. Nine divisions were made in Stress Tolerance Changes corresponding to the several environmental parameters. Expansion of these 23 subdivisions plus the various screening processes resulted in the determiniation of 286 critical issues, specific detailed questions, the answers to which would contribute important information about the biomedical problems of man in space.

2. Background and Current Status

In the 1972-1973 time period, Skylab A is planned for launch. Skylab A is devoted entirely to the performance of research by man in earth orbit and will provide the operational opportunity for gathering limited biomedical data on man in space. The Mercury, Gemini, and Apollo flights yielded limited biological data. The data was collected in conjunction with safety monitoring of the astronauts and pre and post-flight observations; the controls and experimental design desired for precise biomedical research was limited.

Skylab A will include mineral balance and body fluid studies (M071/M073) inflight vectorcardiograms (M092); an inflight assessment of the lower body negative pressure (LBNP) device (M092); a pre and post-flight estimation of changes in blood volume and red blood cell life span (M113); a thorough study of vestibular activities (M131); an EEG sleep pattern monitoring study (M133); a determination of the metabolic rate during calibrated exercise (M171); and two studies on the operation of mass measuring devices, the specimen mass measurement device (M074), and the body mass measurement device(M171).

The Skylab A program will not be able to reveal the time histories of many of the changes. The results of the program will, therefore, be little more than suggestive of the physiological changes that result from weightlessness and will require verification and elaboration in subsequent orbital research programs.

3. Description of Research

The derived critical issues were combined into 10 research clusters for convenience of experiment definition. This consolidation had the advantage of bringing together experimental activities involving common research areas, common instrumentation; and common approaches. The ten defined research clusters are:

1-BM-4	Effects of Weightlessness on Circulatory Function
1-BM-5	Radiation Toxicology and Medical Problems
1-BM-6	Effects of Weightlessness on Stress Response
1-BM-7	Effects of Weightlessness on the Nervous System
1-BM-8	Effects of Weightlessness on Gastrointestinal Function
1-BM-10	Body Fluid Analysis
1-BM-12	Studies on Instrumented Animals
1-BM-13	Effects of Weightlessness on Pulmonary Function
1-BM-14	Effects of Weightlessness on Metabolism
1-BM-15	Centrifuge Studies

Five of the research clusters (1-BM-4, -7, -8, -13, -14) are oriented toward physiological systems or functions; two are oriented toward the use of animals (1-BM-5 uses small mammals, rats and mice, as the only experimental subjects, and 1-BM-12 uses instrumented primates, cats, and dogs exclusively, as experimental subjects). The research cluster on body fluid analysis, 1-BM-10, describes the experimental activities in a clinical analytical chemistry laboratory. Consequently, it includes experimental activities associated with the excretory system, the endocrine system, and hematology and immunology; inflight data on these systems is derived predominantly from chemical laboratory analyses. One cluster, 1-BM-6, involves those activities of many systems which are directed toward the compensatory reactions to environmental stresses. And, finally, 1-BM-15, is instrument oriented, examining those activities associated with research involving an onboard centrifuge.

Experimental activities were categorized according to their potential start dates. Those experiments that could be included in an early space laboratory such as Skylab B were described in detail in Phase II of <u>A Requirements Study</u>

for a Biotechnology Laboratory for Manned Earth-Orbiting Missions, NASA CR111794. Those experiments that are recommended for later space vehicle conduct are detailed in the research cluster descriptions of this report.

The experimental activities were directed toward (1) a determination of the occurrence of a change in physiological function, (2) the time history of the change including the time and degree of its maximum deviation, (3) the mechanisms responsible for the change, and (4) any secondary effects-particularly those resulting in medical problems or stress tolerance alterations.

The types of measurements that are needed to meet the various research requirements of the clusters include: (1) dynamic measurements such as the electrocardiogram, blood pressure, respiratory flows and other variables associated with the energies of the body; (2) static measurements, such as body mass, muscle size, or urine volume, which result in the simple digital accounting of a biomedical statistic; (3) chemical analyses to determine the concentration of a component in a body fluid or tissue sample; (4) conditioning programs designed as counter measures to physiological deconditioning; (5) stress exposures for the purpose of either estimating stress tolerance or of provoking a response in a system in order to measure physiological reserves; and (6) animal studies for techniques and environments unacceptable for human research.

The research in each individual research cluster is described in Appendix C and is summarized in a synopsis associated with each cluster description.

Some of the critical issues related to particular research clusters were not addressed by specific activities described in the cluster description. These critical issues were addressed in three ways:

1. By experiments in related disciplines. The critical issues concerning appetite changes, hunger and satiation, and food preferences (categorized under 1.1.1.1.4.8 Control of Hunger and Thirst) while related to gastrointestinal function are more conveniently investigated by observations and surveys conducted under Man-Machine Research in the area of habitability. Those concerned with waste management, food

management, and water management (designated 1.1.1.1.4.7.3, 1.1.1.1.4.8.3, 1.1.1.1.4.8.5, 1.1.1.1.5.3.3.), were relegated to Life Support and Protective Systems activities.

Various experiments are described in the Space Biology research cluster, "Investigation of Biological Processes in Bacteria, Fungi, Viruses, and Tissue Culture;" fulfilling the information requirements of 1.1.1.2.2.5-"Will changes be produced in the normal characteristics and properties of microbial forms with prolonged exposure to weightlessness?" More extensive work in this research cluster will include host-parasite relationships, the quantitative and qualitative alterations in the normal flora of the crew, the viability and dissemination of bacteria in aerosols, and the susceptibility of laboratory animals to respiratory infections; these studies will contribute to the information requirements of the critical issues 1.1.1.2.2.3, 1.1.1.2.2.4, and 1.1.1.2.2.6 categorized under Microbial Infections.

2. Two critical issues were derived from the long-range objectives, "Define and develop predictive and diagnostic procedures;" these are: 1.1.1.2.4.1, "Can any of the changes observed to occur in relation to physiological deteriorations produced by prolonged exposure to zero g be used as a trustworthy indicator of the onset of deterioration?" and 1.1.1.2.4.2, "Can the variables normally measured in a routine physical examination still be used as indicators of the general health of the subject after prolonged exposure to zero g?" No experiments have been included specifically to satisfy the objective or the derived critical issues. It is postulated, however, that a discriminating examination of the results of the various experiments (particularly those concerned with the mechanisms of a change or the secondary effects of a change) will reveal a number of reactions and responses that are predictive or diagnostic in application. In addition, to evaluate the accuracy of normal diagnostic criteria in space, the results of the routine medical examination of the crew will be compared with their physiological status as revealed by more exact

experimentation.

The long-range objectives in biomedicine indicate that decisions concerning such areas as vibration and acceleration limits, safety limits for toxic inhalants, and gaseous atmosphere requirements should be a part of the biomedical research program. It is assumed that other important environmental factors would be included in this consideration. The critical issues relating to these aspects of the NASA objectives are found primarily in the subobjective concerned with stress tolerance changes (including 1.1.1.3.1.5.2, 1.1.1.3.2.4, 1.1.1.3.3.4, 1.1.1.3.4.4, 1.1.1.3.5.2.6, 1.1.1.3.7.5, 1.1.1.3.8.3) directed toward spacecraft limits for oxygen, carbon dioxide, diluent gases, acceleration, temperature, radiation and toxic contaminants. The limits will be defined from the results of the various experiments on each stress.

By simple observations or subjective evaluations of the crewmen. Many of the critical issues are related to gastrointestinal activities and involve parameters for which, initially, the subjective reaction of the subject is of equal or greater importance than any possible objective measurement. These include nausea, gastric discomfort, and extent of flatulence or eructation. The subject will be instructed to record subjective sensations of this nature.

Other issues involve observations on other subjects including the presence of edema, appearance of the sclera, and color of the nailbeds. The crewmen will be instructed on the procedures for making the required observations. Approximately 13 critical issues may be satisfied by simple observations or subjective evaluations.

4. Impact on Space craft

The only unusual requirements biomedical experiments will impose on the environmental control and life support (ECLS) systems of the spacecraft are a separate and individual ECLS system for the animal holding facility and individual animal research modules. The experiments utilizing man as a subject are compatible with the normal ECLS requirements for crew habitation. Some environmental extremes are required for stress exposure but these will be produced in micro-environments and will not impact the spacecraft system.

For most of the described experiments, six crewmen are desired, although it would be possible to modify the program to utilize only three. The reduction would, however, significantly extend the program. The measurement frequency will be highest early in each crew cycle, during anticipated periods of maximum change; the frequency would be reduced later in the cycle if the alteration plateaued.

The weight,power, and volume requirements are not additive, since the various described experiments are not intended to be conducted simultaneously, but over a span of 7 to 10 years. In general, biomedical research equipment will not heavily impact the spacecraft systems; major exceptions to this rule would include signal conditioning, display, and recording equipment; analytical instruments associated with the chemical laboratory; the LBNP device, bicycle ergometer, and rotating litter chair; and, primarily, the onboard centrifuge (which will cause, by far, the greatest impact). Each of the above items is more fully discussed in the research cluster description to which it applies.

Most experiments described in the biomedical research program will benefit greatly from the participation of a well-trained and experienced biomedical technician, although many may be performed without difficulty with only cross-trained crewmen. A few of the procedures could have undesirable consequences if not performed correctly. For these procedures a well trained medical corpsman should be available in case of an emergency.

5. Required Supporting Technology Development

For many of the experimental activities described for biomedicine, the techniques and equipment required for their conduct are presently available; for others, some form of supporting technology development(STD)was required. Twelve STD items were identified for the research program. Four studies were specified for the definition of (1) inflight body fluid analysis, (2) techniques for non-invasive central venous pressure measurement, (3) a radiation source for the exposure of small mammals, and (4) sensor selection for instrumented animals. Two items involved the maintenance of experimental animals in space in a general holding facility and in individual experimental modules. The remaining six items involved experimental equipment (such as a quantifiable measurement of spinal reflexes) which is either not available in terrestrial laboratories or not compatible with spacecraft use such as a body volumeter. These requirements are detailed in Section 6 of this report.

SUBDISCIPLINE SYNOPSIS

1-BR

Behavioral Research

1. Research Objectives

A pervading objective in this subdiscipline is to assay and to continue to assure man's ability to function as a doer of activities in space. This is to be accomplished through determining the effect of the space environment on (a) man's basic capabilities such as vision, hearing, reaction time, and finger manipulation; (b) his performance on combinations of these primary characteristics as utilized in complex operational and maintenance type tasks; (c) the acquisition and retention of critical skills needed in extended space flight; and (d) crew attitudes and moods, productiveness, and verbal and physical interactions (particularly as affected by crew size, length of mission, variations in habitability design of the spacecraft, and characteristics of invididual crew members). Research will be done in the following areas:

1-BR-1 Sensory, Psychomotor, and Cognitive Behavior-emphasizing primary capabilities in five areas; vision, hearing, psychomotor, cognitive and orientation.

1-BR-2 Crew Structure and Composition-emphasizing the study of the crew in extended missions, characteristics of individual crew members, and variations in spacecraft habitability design as revealed by crew verbal and physical interactions, productiveness, attitudes and moods.

1-BR-3 Complex Task Behavior-emphasizing performance on real mission operational and maintenance tasks of a complex nature both inside and outside the spacecraft under zero gravity and various levels of gravity.

1-BR-4 Skills Retention-to identify those skills which degrade in the space environment, the time and course of their degradation, ways for preventing such degradation, and procedures and/or equipment for maintaining critical skills in space.

1-BR-6 Performance Measurement-to evaluate various methods of assessing human performance in space.

2. Background and Current Status

Earth experiments have shown that physiological deconditioning generally is accompanied by degraded performance on visual tasks, degradation in coordination and psychomotor capabilities, slowed reaction time, and degraded performance on perceptual patterns of spatial orientation. Brief space flight experiences have shown physiological deconditioning in the form of losses of body fluids, bone, and vascular reactivity. Detailed measurements have not been made of man's sensory, psychomotor, and cognitive performance during space flight.

Considerable information has been gathered while man accomplished operational and maintenance activities in space, even such complex activities as manual reentry when automatic systems failed. However, hard research data has not been gathered. Measurement of human performance on complex tasks in space is required to determine (1) how man will perform under the conditions of extended space flight, (2) how his performance changes as a function of mission duration, and (3) differences in performance among crewmen of different backgrounds and training. The available training literature contains a great amount of data on skills which degrade most rapidly, on requirements for periodic retraining, and on the usefulness of task simplification and retention aid techniques in preventing degradation. However, for extended space flight there is a considerable gap in knowledge regarding (1) maintenance of proficiency for extended periods under space conditions; (2) the specific characteristics of any degradation that might occur; (3) the frequency with which retraining should occur; and (4) the form (such as rehearsal or warmup) which such re-training should take.

A major coordinated effort is needed to assay the potentials of and the influence of space flight on group behavior. Empirical data are needed from repeated observations in space and on the ground of crews of different size and composition to determine the influence of long duration confinement on the crew interaction processes; the structuring of group roles; and the development of and changes in individual attitudes and personality characteristics, particularly as they affect crew productivity, interpersonal conflict, and mission success.

3. Description of Research

For measuring crew performance on activities in space, the crew-centered behavioral research program provides five research clusters which are identified in paragraph 1, with detailed descriptions provided in Appendix C. Measurements will be obtained using self-administering tests taken in an area that is relatively free from distractions; many other measurements will be obtained by recording and analyzing performance of crew members on a noninterference basis while they accomplish their day-to-day activities about the station.

Titles of measurement parameters should help communicate the kinds of research activities involved. Examples of parameters used to measure vision include acuity, depth perception, and recovery from glare, audition includes absolute threshold, sound localization and movement; orientation includes real and illusory movement; cognition includes perception, recall, and reasoning; psychomotor includes tracking, fine and complex motor abilities, and limb strength; complex task performance parameters include task times, errors, and subjective descriptions of hardware design difficulties; skills retention utilizes measurements of task time and error; crew structure and composition includes measurements of verbal and physical interaction and crew mood. Measurements in these last three research areas generally will be obtained on a noninterference basis while the crew accomplishes its day-to-day station work activities.

4. Impact on Spacecraft

The major impact of the behavioral research program is on the time of crew members as experiment subjects. Supporting equipment requirements vary greatly, but a "worst case" example of high demand on the spacecraft is provided by the centrifuge: 1720 pounds, 2000 cubic feet, and 5300 watts of peak power.

5. Required Supporting Technology Development

This research program calls for the gathering of baseline data on subjects prior to launch. If various orbital stresses are simulated and their effects studied experimentally prior to the initiation of the flight crew's research program, data comparisons will have improved validity. Prelaunch analytic studies are required to obtain detailed descriptions of Operator, Maintenance, and Scientific Investigator tasks. Potential training equipment and retention aids must be identified and development in simulation facilities on earth. The Crew Structure and Composition research will require carefully controlled ground experiments to refine techniques for obtaining and analyzing video and audio records of group performance.

SUBDISCIPLINE SYNOPSIS

1-MM

Man-Machine Research

1. Research Objectives

The experimental activities proposed in the Man-Machine subdiscipline of Manned Space Flight Capability are described in this synopsis under five research clusters: 1-MM-1 "Controls and Displays"; 1-MM-2 "Locomotion and Restraint"; 1-MM-3 "Habitability"; 1-MM-4 "Work/Rest/Sleep Cycles"; and 1-MM-5 "Performance Aids."

The primary objective of the research included in this subdiscipline is the verification under actual space conditions of extended duration, weightlessness, and artificial gravity of design principles identified and developed for previous manned space flights and in ground-based research and simulation. It is addressed to the accumulation of data about the interfaces between man and equipment to establish design criteria; examples include controls and displays; living, working, recreational, and sleeping accommodations; locomotion and restraint devices; tools, manipulators, and other job aids for enhancing crew performance; and schedules for work, rest, and sleep. A secondary objective is evaluation of man's capabilities and limitations while interfacing with such equipment.

The specific research required in this subdiscipline is in response to 72 critical issues identified during in-depth analysis of the following long-range objectives:

A. Identify requirements and develop equipment and procedures to assure the effectiveness of man in the pursuit of science experiments, applications tasks, and vehicle operations such as telescope operations, laboratory techniques, extravehicular activities, rescue, docking, and cargo handling.

B. Develop equipment and technology for habitable living areas, crew and cargo transfer, assembly, and maintenance internal and external to the space vehicle and on extraterrestrial surfaces.

C. Identify needs and develop ways and means to capitalize on man's abilities and on his participation as an experimenter and operator.

D. Conduct tests and studies pertinent to the development of design criteria for habitation, life support, and protective equipment for men in long-duration space operations.

E. Develop and demonstrate under operational conditions suitable EVA and IVA modes of operation for routine and emergency activities.

F. Design, develop, and flight test critical long-lead items and procedures required for planetary missions; obtain data pertinent to the establishment of design criteria for manned systems that are required to perform over planetary flight time periods and verify proposed operational techniques for the conduct of such missions.

2. Background and Current Status

Human Engineering, the discipline primarily concerned with design of equipment with which man interfaces, has contributed, through research, design criteria for ground and aircraft applications in controls and displays, work places, living areas, tools, and job aids. It is generally agreed that the bulk of these design criteria can be applied directly to the equipment to be operated in space.

An important source of knowledge applicable to space flight resides in the terrestrial experience with ships and submarines, isolated industrial sites such as off-shore oil rigs, artic and antarctic exploration, and military aircraft operations.

In the past few years, ground-based research directed specifically at space problems of long duration confinement, weightlessness, reduced sensory input, high acceleration and vibration, and stresses of vehicle rotation has expanded considerably. This research has been in NASA centers, Navy and Air Force laboratories, industrial sites, and universities. Space conditions have been simulated by underwater immersion, parabolic aircraft flights, airbearing and suspension devices, rotating rooms, short and long radius centrifuges, and environmentally controlled confinement chambers.

It is concluded that reasonable confidence can be placed in design that is based on present knowledge, but that in-space verification is necessary.

3. Description of Research

The research contemplated in this subdiscipline spans a period of nine years of in-flight observation. A continuing long-range effort is necessary to obtain repeated measurements on different types of vehicles, with crews of different size and composition, and under different mission conditions.

Most of the research can be conducted through observation and measurement of ongoing operational activities as the crew interfaces with mission equipment. However, it will be necessary for the crew to perform experimental or simulated tasks (1) in cases where exposure to the real task involves hazard, (2) if advanced equipment to be evaluated is not yet qualified for operational use,

(3) when the task to be evaluated is one which is unpredictable in occurrence, or (4) where the equipment to be evaluated is for unique use on advanced missions such as planetary or lunar flights.

Man-machine research has been divided into five research areas, each of which is described briefly on the following page.

A. 1-MM-1 Controls and Displays

This research is to verify the design adequacy of advanced displays (such as plasma, liquid crystal, light-emitting diodes, and interactive displays); controls (such as capacitance controls, controls for interacting with computer and cathode ray tubes, and controls integrated with displays); and control/display panel layouts for use under weightlessness and various levels of artificial gravity. Inflight verification of ground-developed criteria will consist of direct observation (by another crewman or by TV camera) and crew subjective evaluation during operational use of controls and displays. Experimental sessions on advanced controls and displays will be designed to last approximately 30 minutes. They will be repeated several times during a particular crew cycle to obtain data under different conditions and with different crew members. Measurement data will include task time, reaction times, errors, and subjective comments by the crewmen involved.

B. 1-MM-2 Locomotion and Restraint

Locomotion and restraint devices and procedures for using them, as developed in ground-based simulations, will be evaluated for design adequacy in this research. Powered and unpowered devices, devices for EVA as well as IVA use, and restraint equipment for use at various work locations will be evaluated under conditions of weightlessness and partial gravity. Data on energy expenditure, impact forces exerted, accelerations generated, and time for completion of locomotion and restraint tasks will be collected by means of instrumentation and through subjective comments of crewmen subjects. Data analysis and assessment will be done on the ground and on-board as the techniques are developed.

C. 1-MM-3 Habitability

The objectives of this research will be achieved by in-space evaluation of crew use of habitability features provided on the basis of ground research, simulation studies, and previous manned space flight experience. Habitability features of interest include architecture (volume, configuration, orientation), environment (atmospheric, color and decor, lighting, acoustics), food and water management facilities, personal hygiene and housekeeping accommodations, and off-duty facilities (ward rooms, sleeping, and recreational areas). Data will be obtained during normal crew activities by direct observation (TV or motion picture cameras), analysis of selected biomedical and behavioral data, and by analysis of crewman comments. Analysis of the specific measurement parameters to be obtained should provide information on the effect of various habitability configurations on crew physical health, work efficiency, and attitudes and motivation. Data collected in this research cluster will be closely correlated with that obtained in Research Cluster 1-BR-2 Group Dynamics.

D. 1-MM-4 Work/Rest/Sleep Cycles

In this long-range research, inflight data (using noninterference techniques) will be collected on crew circadian rhythm and diurnal cycles, length and depth of sleep, work efficiency with varying work shift arrangements, and crewman responses to simulated emergencies when awakened from sleep. Biomedical and behavioral data such as cardiovascular activity, brain wave (EEG), body temperature, metabolic rate, blood chemistry, fatigue, level of attention and concentration, and work efficiency along with subjective comments of crew will be collected on a continuing basis for periodic analysis.

E. 1-MM-5 Performance Aids

This research will demonstrate and verify ground-based evaluations of equipment (tools, remote manipulators, optical aids, and job aids) provided to assist man in performing space tasks in maintenance and repair, experiment operations, and data handling with the goal of producing sound, verified design criteria for equipment of this type.

- Observational, instrumented, and subjective crew data will be obtained, preferably during crew operational activities using these devices, but augmented with simulated tasks where necessary. Data will be collected on task times and errors, energy expenditure, forces and torques, difficulties encountered, and adequacy of the devices in enhancing crew performance. These data will be collated and analyzed for future use.

4. Impact on Spacecraft

Weight, volume, and power impact for man-machine research is tabulated below for the five research clusters. Though used in most of the research clusters, the TV and audio measurement and recording impact is shown only for 1-MM-3. The impact of providing EEG measurement capability is included in 1-MM-4.

Research Cluster	Weight (lb)	Volume (cu ft)	Average Power (watts)
1-MM-1	750	336.0	350
1-MM-2	100	64.0	40
1-MM-3	93	4.77	90
1-MM-4	20	1.0	50
1-MM-5	185-305	20.3-25.3	60-120

The major logistics impact is in the resupply of magnetic tape and graph paper. Additional logistic requirements involves the supply of advanced equipment and the return of outmoded equipment to earth, plus the reconfiguration of operational and experimental work stations as the experimental program continues.

Crew time impact is minimal since data gathering will be accomplished primarily on an observational, noninterference basis. For a nine-year research program, the allocation of crew time for each research cluster and for different experimental activities is as indicated in the table below.

Research Cluster	Experimental Subject(hr)	Other Experimental Activities (hr)	Total (hr)
1-MM-1	390	1,393	1,783
1-MM-2	48	760	808
1-MM-3	0	334	334
1-MM-4	0	1,173	1,173
1-MM-5	360	606	966
Total	798	4,266	5,064

5. Required Supporting Technology Development

To adequately implement the research described in this subdiscipline, a forceful, long-range ground research and development program is needed. Controlled, repeated, and centrally coordinated ground simulation is necessary for all the experimental tasks identified. This ground simulation should take advantage of the simulation techniques and facilities available in the government, industrial, and university community and should include water immersion, zero-g aircraft, slow rotational facilities, and confinement chambers.

A major research and development effort is required to develop and refine equipment and procedures for noninterference assessment of the man-machine interface. Equipment such as unobtrusive biomedical measurement systems, TV and audio recording systems require extensive research attention. Techniques and procedures must be developed and verified on the ground for converting the data from these instruments to meaningful, quantifiable evaluations.

Specific items of equipment which require development effort include: portable metabolic analyzers which can be worn by crewmen with minimum encumbrance and provide accurate metabolic data; miniaturized accelerometers with integral transmitters which can be worn on the crewman's body while performing locomotion tasks; universal flexible task boards for task simulation in space which have the capability of being used over long periods of time for a variety of experiments; space-qualified bilateral master/slave electric remote manipulators having less weight, volume, and power requirements than present ground versions;

and optical aids for enhancement of man's performance in space visual tasks.

SUBDISCIPLINE SYNOPSIS

1-LS

Life Support and Protective Systems

1. Research Objectives

The major objectives of these research clusters are (a) to obtain basic experimental data for the design of mass and heat transport equipment subject to a low "g" environment and (b) to test and evaluate advanced life support processes, components, and subsystems operating in a zero-g environment for long durations. The research is described in the following research clusters:

- 1-LS-1 Phase Change and Thermal Processes
- 1-LS-2 Material Transport Processes
- 1-LS-3 Atmosphere Supply Processes
- 1-LS-4 Water Management
- 1-LS-5 Water Electrolysis
- 1-LS-6 Food Management and Processes
- 1-LS-7 Atmosphere Purification Methods
- 1-LS-8 Life Support Monitoring and Control
- 1-LS-9 Waste Management
- 1-LS-10 Heat Transport Equipment
- 1-LS-11 Crew Equipment and Protective Systems
- 1-LS-12 Life Support System Maintenance and Repair

2. Background and Current Status

The first two experiments, 1-LS-1 and 1-LS-2 are necessary because Life Support Systems utilize the basic processes of mass and heat transport such as boiling and condensing. Theory to date has been developed based on short duration low "g" tests using drop towers or flight vehicles. However, the long-term empirical data available on these processes for low and zero-g conditions is inadequate as a basis for confidently designing the hardware components comprising a Life Support Subsystem.

The remaining experiments are oriented toward testing and evaluating the performances of processes, materials, components, and hardware comprising a Life Support System. In order to reduce the system weight by reducing the expendables inventory, a number of processes have been proposed for recovering water and oxygen from the biowastes. Many of these have already been bench-tested or have been evaluated in long duration space vehicle simulation tests. Included are the Sabatier oxygen recovery system which has undergone a 90-day test in the NASA McDonnell Douglas Space Station Simulator, the vacuum distillation-vapor filtration waste water recovery system, the asbestos-matrix KOH vapor feed system for water electrolysis, and the solid amine and molecular sieve CO_2 concentrator systems.

Some advanced food storage and processing methods have already been tested in the Apollo program. Bioregeneration which has been studied is currently stalemated through product unacceptability. Under NASA sponsorship there is being developed a waste management system incorporating commodes which feature wet and dry-john techniques with waste slurry drying by incineration or vacuum.

Only limited experimental work has been done in the past in heat transport under zero g using single and multiple loops; however, the 90-day NASA/MDAC Space Station Simulator test did use a complex heating and cooling system with a simulated space sink.

Highly sensitive fire detection systems have been developed for space application. The technology for the detection of contaminants is in need of further development; further work is also needed for the rapid detection of bacteriological materials and trace contaminants.

In various stages of development are space suits for emergency and long duration EVA.

In the area of Maintenance and Repair, NASA has supported studies to establish guidelines for such areas as maintenance, spares, parallel-redundance, and modularity. Data accumulated from the 90-day Space Simulator test is being evaluated. Zero-g testing is still required to verify procedures and test repair equipment.

The need for an efficient compact Data Management System has long been recognized by NASA and studies have been made or are in progress for the definition of such a space system. These include studies by MIT on a dual computer configuration, and a commercially developed transient effects computer study for an integrated life support system (ILSS) automatic controller design.

3. Description of Research

The basic experiments 1-LS-1 and 1-LS-2 will be performed in a fully instrumented heat transfer and fluid mechanics scientific laboratory or small unmanned satellites. There the nucleate boiling will be studied from surfaces immersed in a liquid tank, while the two-phase condensing phenomena is studied in transparent tubes; high-speed cameras and TV will be used for visual aids and the studies will be performed under constant observation by the test personnel. The tests of Life Support components, processes, and subsystems will be performed in test facilities containing automated instrumentation for monitoring and control of the input and output parameters such as temperatures, pressures, and fluid flow. The subsystems will generally utilize the black-box approach. Testing of Life Support Equipment will be accomplished in manned and unmanned spacecraft prior to actual use.

The life support subsystems and processes to be tested include water recovery, oxygen recovery, CO_2 collection, water electrolysis, atmosphere purification and regulation, heat transport loops, waste management and food management.

The crew equipment and protective systems test will occur in a specially designed hazards laboratory fully isolated from the rest of the spacecraft and containing remote handling equipment. There, evaluation will be conducted of the fire detection and extinguishing techniques, fluid spillage and cleanup, line and tank rupture repair, and space suit testing.

The food management tests will involve the cooperation of the crew in evaluating the food storage and preparation techniques and may be integrated with the baseline system; the production of edible proteins from biowastes, utilizing advance chemical or microbial techniques, will be carried out when an acceptable product can be produced.

The large amounts of data obtained from the instruments, sensors, test equipment, and from crew observation and response will be fed to a Data Management System where recording, processing, display, analysis, storage, telemetering, and control will be exercised.

4. Impact on Spacecraft

The impact on the spacecraft is variable depending on the type of experiment. Thus, of all of the experiments, only the first two basic investigations require careful control of "g" level, but for only relatively short time periods during the test.

The estimates for peak power, weight and volume requirements are shown in Table 3-6. The large power and weight requirements of 1-LS-6 are due to the proposed bacteriological food regeneration work. The spacecraft will provide the regulated power and will provide corresponding thermal heat removal capability.

With some proven reliability, the life support subsystems will replace or augment the baseline subsystem. In general the subsystems tests will be fully automated both for control of parameters and specimen test sampling. Minimal demands are thereby placed on the crew's time for routine monitoring and maintenance. The basic experiments, however, will require continuous crew involvement during the test period.

Table 3-6

EXPERIMENTS IMPACT

Experiment No.	Peak Power (watts)	Weight (lb)	Volume (ft^3)
1-LS-1	1500	300	
1-LS-2	1500	500	30
1-LS-3	1000	--	24
1-LS-4	700	400	20
1-LS-5	700	450	48
1-LS-6	6000	1700	100
1-LS-7	400	300	30
1-LS-8			
1-LS-9	500	900	100
1-LS-10	1000	700	40
1-LS-11	500		1000

5. Required Supporting Technology Development

Requirements for these research clusters include:

A. Development of flight weight instrumentation for rapid chemical, microbial and potability testing by automatic means and monitoring and process control.

B. Development of peripheral equipment for rapid data reduction, correlation and interpretation.

C. Development of materials, catalysts, liquid vapor separators, filters and screens to operate in zero-g for long time periods with minimum replacement requirements.

D. Improved methods for separating O_2 and H_2 evolved gases from water electrolysis.

E. Development of improved methods for food storage, containers and food regeneration.

F. Development of light weight mass handling components such as vacuum pumps, accumulators, valves, and regulators.

G. Development of zero-g heat transport hardware.

H. Development of tools and equipment for zero-g repair, maintenance and spillage clean-up.

SUBDISCIPLINE SYNOPSIS

1-EE

Engineering Experiments

1. Research Objectives

Engineering experiments are subsystem-oriented space activities (research clusters) designed to test and evaluate advanced Data Management, Structures, Stabilization and Control, Navigation and Guidance, and Communications components and assemblies; the objective is to obtain engineering design data, space operating characteristics, and man-machine performance data useful to the designers and planners of advanced manned space vehicles and missions. Similar objectives for Life Support Systems are included in a separate set of research clusters (1-LS-1 through 1-LS-12) and summarized in the Subdiscipline Synopsis 1-LS.

The research described in the five research clusters comprising this subdiscipline was identified through detailed in-depth analysis of NASA long-range objectives and ongoing programs. During this analysis 75 critical issues were formulated, each being partially or wholly responsive to one of the following NASA long-range objectives.

(A) Develop equipment and procedures to assure the effectiveness of man in the pursuit of science experiments, applications tasks, and vehicle operations;

(B) Design, develop, and flight test critical long-lead items and procedures required for planetary missions;

(C) Develop long-duration systems that use high-reliability components to minimize resupply and repair requirements.

(D) Fly an operating space facility module continuously for durations typical of planetary flight times to obtain data pertinent to the establishment of design criteria for manned systems.

The hardware of interest in this subdiscipline is restricted to (1) advanced components which require verification before commitment can be made to final design; (2) components which are designed for unique applications on advanced missions (such as planetary) and cannot be incorporated into the operational orbiting vehicle systems; and (3) classes of hardware, such as advanced gyros, for which increased space operating characteristics data is needed (engineering handbook data). Achievement of the NASA long-range objectives and implementation of the specific research included in Engineering Experiments will require a long-term in-space engineering research facility having sufficient capability and flexibility (1) to accept many different configurations of space flight hardware, (2) to handle the large amounts of engineering data generated, and (3) to provide for rapid inflight modification of equipment under test.

2. Background and Current Status

Background for the research described in Engineering Experiments includes significant experience from both manned and unmanned space programs and a substantial backlog from ground testing in engineering laboratories throughout the world. The objectives of the Mercury, Gemini, and Apollo programs were primarily engineering oriented; thus, these programs have contributed basic knowledge, feasibility demonstration, and in-space verification for the subsystems of concern-Data Management, Structures, Stabilization and Control, Navigation and Guidance, and Communications. Basic theory for most of the subsystem components of interest is well established and in many cases experimental designs of hardware have been completed.

In Data Management much experience with the man-to-computer interface has been gained in the manned space program. Many of the advances required in data management, however, have not been explored in space. Microfilm processing and retrieval, onboard data editing and compaction by man, and photographic film processing are examples of areas which require considerable ground-based development and test, along with inflight verification.

The feasibility of advanced structural concepts (deployable, expandable, extendable structures) have been demonstrated in both manned and unmanned space flightswith small sensors, antennas, and power generating devices. However, mechanisms for deploying, orienting, and rotating larger structures, as well as problems with large diameter dynamic space seals and with lubricant stability under space conditions, require space investigation.

Stabilization and Control attitude reference sensors, including gyros, laser gyros, telescopic sensors, and electromagnetic suspension systems are in various stages of development. Pointing capabilities of a few arc seconds have been demonstrated for magnetic suspension systems. Skylab A experiments will measure forces imparted to the spacecraft by typical crew motion disturbances and will provide valuable experience with control moment gyros. Biowaste propellant systems are in development, but have not yet been flown.

Navigation and Guidance theory is well established and the feasibility of navigation by satellite has been demonstrated for ground based and shipboard use. Landmark trackers have been used on Apollo missions for both earth and lunar landmark tracking. Optical Communications systems are within present development capabilities, although they have not yet been tested in space for communication over long distances.

3. Description of Research

The research clusters comprising Engineering Experiments are addressed to the evaluation of advanced subsystem components and assemblies which require testing under the unique conditions of space to (1) obtain engineering data for improved design, (2) verify achievement of design performance goals, and (3) demonstrate man-machine compatibility. Many of the subsystem elements to be tested will be capable of being placed on line to replace or augment baseline systems during periods of experimentation; during these periods the proven operational hardware would act as backup. The usual engineering measurements will be obtained to assess hardware performance. In addition, man's capabilities will be utilized in visual inspections for equipment wear and damage, for taking and testing items such as lubricant samples, and in identifying necessary changes in experimental protocol.

Engineering Experiments were described in detail in five research clusters and a brief description is given below.

(A) 1-EE-1 Data Management

The questions to which the critical issues in this research cluster seek answers involve hardware (and man's interface with that hardware) for storing, retrieving, displaying, and processing the vast quantities of data which inorbit experiments will generate. Since it is felt that reasonable confidence in the operational effectiveness of such hardware can be achieved in ground-based tests, the inflight problem becomes one of verification of hardware and procedures worked out on the ground. For this reason no detailed description was prepared for this research cluster; however, the details of inflight verification are contained in Operations Experiments Research Cluster 1-OE-5 "Vehicle Support Operations."

(B) 1-EE-2 Structures

In this research cluster experimental hardware will consist of portions of structural systems, scaled down versions of large structures, or prototypes of deployable, expandable, and extendable systems. Operating parameters will be monitored for (1) extendable booms for positioning various lightweight sensors, (2) automatic deployment mechanisms for large rigid structures such as solar cell arrays and antennas, (3) small diameter dynamic seals for rotating booms supporting solar cell arrays, (4) prototype expandable structures such as airlocks, connecting tunnels, maintenance hangars and experiment bays, and (5) large diameter dynamic seals for rotating sections of space craft. Parameters include temperatures, pressures, voltages, currents, speeds of rotating machinery, friction coefficients; dimensions of deployed and retracted structures, and crew performance in interfacing with structures.

(C) 1-EE-3 Stabilization and Control

Stabilization and Control research is described in three research clusters: 1-EE-3-1 "Gyroscopic Attitude Controls," 1-EE-3-2 "Disturbance Torque Measurements," and 1-EE-3-3 "Biowaste Electric Propulsion." Research involves (1) testing of various advanced type attitude reference systems and accelerometer devices mounted in the spacecraft or detached modules; (2) defining acceleration disturbances inherent in spacecraft operations; and (3) testing space vehicle control systems. Parameters to be measured in attitude reference systems include gyro drift, gyro gimbal angles, rates, rate of spin, and the error inherent in these measurements. Acceleration disturbances will be measured by mounting accelerometers in the spacecraft to sense and feed the data to a computer for subsequent analysis. Biowaste, or other control systems, when operated in the experiment would replace or augment the baseline control systems for varying lengths of time during which performance data would be taken.

(D) 1-EE-4 Navigation and Guidance

This research cluster deals with (1) evaluation of selected components, elements, and subsystems for performing navigation and guidance functions for a manned space flight vehicle and (2) evaluation of the part man can play in enhancing and optimizing the operation of these subsystems. The following four specific research clusters covering different techniques of obtaining navigation data are described: 1-EE-4-1 "Onboard Laser Ranging"; 1-EE-4-2 "Interplanetary or Translunar Navigation by Spectroscopic Binary Satellite"; 1-EE-4-3 "Landmark Tracker Orbital Navigation"; and 1-EE-4-4 "Navigation/Subsystem Candidate Evaluation".

(E) 1-EE-5 Communications

This research cluster will evaluate the ability of an optical communication system to maintain communications in the presence of operational disturbances such as spacecraft quiver, high relative velocities of receiver and transmitter, extraneous light from earth, sun, moon, and occultation. Experimental communication will be between a manned spacecraft in earth orbit and a deep space vehicle (DSV).

A laser on board the DSV generates a constant wavelength signal which is modulated by a Pockels cell, with the signal being focused and aimed by a telescope on the DSV. The signal is received by a telescope on the spacecraft, demodulated by a detector, amplified by a receiver, and fed into a correlator to compare the received signal with a stored signal.

4. Impact on Spacecraft

The weight, volume, and structural impact of Engineering Experiments can be considerable depending on the specific experimental hardware to be flown. Some mechanisms described in the Structures research cluster alone would weigh between 1500 and 2000 pounds. All experiments will require structural mounting and some items require penetration of the spacecraft shell. Viewing ports are also required for some of the research clusters. Power requirements in total are substantial, but by judicious scheduling, average power should not exceed 500 watts.

Though it is assumed that experiments on free-flying modules would be of the noninterference type, there would be an impact of these modules to provide equipment mounting accommodations, retrieval of experimental specimens, remote monitoring, and data transmission to the spacecraft.

The large amounts of engineering data generated in these experiments will place a substantial load on the data management system for processing and storage of experimental data, as well as for the storage and retrieval of reference data.

A major impact involves the incorporation of spacecraft capability for switching the experimental hardware on line to augment or replace operational components, assemblies, and systems.

5. Required Supporting Technology Development

For an optimum inflight data management system considerable ground based development and test is required of microfilm and photo processing equipment for zero g; included are devices for compressing data, and for viewing, editing, cropping, and selectively transmitting data (such as filmed terrain observations), along with devices for providing enhanced manned communication with computers.

Ground based development and test of a flight-rated biowaste resistojet is required prior to flight experiments; state-of-the-art advancements are needed in onboard laser ranging systems and landmark tracking systems; prior to the inflight communications experiment described in research cluster 1-EE-5, an integrated optical communications transmission and receiver system must be developed; also, advancements must be made in capabilities for accurate pointing and acquisition of a laser beam over large spatial distances.

SUBDISCIPLINE SYNOPSIS

1-OE

Operations Experiments

1. Research Objectives

Operations experiments encompass those in-orbit activities concerned with the verification and evaluation of manned space operations in the areas of logistics and resupply; maintenance, repair, and retrofit; assembly and deployment; module operations; and vehicle support operations. They address themselves to the evaluation of the equipment, procedures, and crew skills of which any operation is comprised. The objective of the Operations Experiment subdiscipline is to critically examine in space those operations which have been developed and designed on the ground, scheduled for specific space missions, thoroughly investigated in ground simulation facilities, and for which flight crews have been given extensive training.

Eighty-two critical issues are answered by the research described in the research clusters making up this subdiscipline. The critical issues were identified by indepth analysis of the following long-range NASA objectives:

A. Develop and gain operating experience related to the resupply and maintenance of multimanned space stations: this would include the resupply of expendables as well as equipment and experiment payloads.

B. Develop operator equipment and technology for maintenance internal and external to the space vehicle.

C. Develop and demonstrate under operational conditions suitable EVA and IVA modes of operation for routine and emergency activities.

D. Define and develop a modular space station concept which offers flexibility to adapt to changing mission requirements and payloads.

E. Identify requirements and develop equipment and procedures to assure the effectiveness of man in the pursuit of science experiments, applications tasks, and vehicle operations.

F. Develop and operate manned spacecraft modules that can support space operations by (for example) providing services to satellites or to remotely operated modules.

G. Identify requirements and develop techniques to conduct activities in support of major scientific and applied disciplines.

H. Develop space vehicle modules that can support laboratories and observatories for the pursuit of science, applications, and technology goals.

2. Background and Current Status

For all of the operations of interest in this subdiscipline a base of knowledge exists from which mission planners and designers can draw with varying degrees of confidence. The relevance of this knowledge base runs that gamut from remote (construction industry experience as applied to inspace assembly) to highly pertinent (rendezvous and docking experience in the Apollo program).

Gemini, Mercury, and Apollo flights have contributed insight into the potential difficulties in logistics, resupply, and emergency operations. Transfer of equipment items between the Apollo Command Module and the Lunar Module and between the Lunar Module and the surface of the moon have identified some of the problems of cargo transfer. Information on large cargo transfer and on transfer of liquids and gases has not, however, been acquired in space.

Manned spaceflights have demonstrated that IVA space maintenance is feasible, given the proper tools, aids, astronaut training, and proper design of the prime equipment. The EVA maintenance problem is more complex and will require much ground simulation research and the development of optimized equipment and procedures. Applicable knowledge is available from aircraft inflight maintenance experience, and much additional relevant data will come from the Skylab A flights.

Assembly and deployment of large structures in space is an attractive and perhaps quite necessary concept, but one in which little inspace experience has been gained. It is expected that Skylab A will contribute significant knowledge in this area, but a great deal of Earth-based training and practice, using underwater simulation and other approaches, is necessary before operational commitments can be made.

Relevant background knowledge in module operations from a manned spacecraft is relatively sparse. For some specific aspects, such as rendezvous and docking, the experiences in Apollo are extremely valuable. Special module studies have been conducted to identify desirable types of experiments, characteristics of experimental modules, and optimum modes of operation. The background in ground control of unmanned satellites is also voluminous and should contribute to understanding of this problem. The common problems of module operations include rendezvous and docking, communication between module and manned vehicle, deployment and retrieval, and maintenance.

Experimentation in vehicle support operations can draw heavily on earth-based experience, particularly for supplying similar services such as medical, food, data, and communications; however, many questions remain unanswered. They include (1) identification of the crossover points at which centrally supplied services become attractive, (2) appropriate procedures and equipment for supplying services, and (3) the crew skill mix necessary to adequately supply support services.

Much of the research activity in this subdiscipline involves extravehicular activity (EVA) by the crew. A great deal of background knowledge and experience has been accumulated in ground-based water immersion simulation, in aircraft flights taking advantage of short periods of zero g while in Keplerian trajectories, and in the Gemini and Apollo flight program. Skylab A will undoubtedly contribute major knowledge in this area. A program of carefully controlled observations of Skylab A activities is necessary to refine EVA techniques for long-duration space flight.

3. Description of Research

The research described in the five Operations Experiment research clusters can be termed controlled observation of the real world. It uses observational techniques to verify and evaluate routine operations as they occur. These techniques, similar to time and motion study, use direct observation by TV or motion picture cameras, instrumentation of the equipment with which crewmen interface, subjective comments of the crewmen participants, and biomedical instrumentation for related physiological data.

Each of the research clusters is described briefly below.

A. 1-OE-1 Logistics and Resupply

Logistics and Resupply is divided into two subclusters: 1-OE-1-1, which is addressed to methods of transferring, handling, and storing packaged cargo, fluids, and large pieces of equipment; 1-OE-1-2, which is concerned with emergency and rescue operations both inside and outside the spacecraft. In both subclusters, evaluations of convenience, effort, and time will be made by obtaining data on crew task time and error, ease of performing operations, difficulties encountered, required skill levels, energy expenditure, and incidents of damage or injury. Emergency and rescue operations will be simulated and where appropriate anthropomorphic dummies will be used to simulate incapacitated crewmen.

B. 1-OE-2 Maintenance, Repair, and Retrofit

This research effort is confined to observation and measurement of maintenance, repair, and retrofit operations conducted as a normal part of operating the in-orbit space vehicle. Since opportunities for such observation will occur in practically any of the other experiments described in this study, detailed research cluster descriptions were not prepared for 1-OE-2. Observational methodology will utilize TV cameras, timers, biomedical instrumentation, and crew subjective reports to obtain data on task times and errors, energy expenditure, difficulties encountered, and crew evaluations.

C. 1-OE-3 Assembly and Deployment

This research area covers all operations in assembling and deploying large structures in space, including such items as unfurlable antennas, expandable structures, erectable booms, mechanically deployed structures, and large telescopes. In general the observation and measurement effort will be divided into two phases; the first is the construction phase, while the second is a span of time during which the effectiveness of the construction will be assessed by evaluating the operational efficiency of the assembled structure. Experimental data will be used to evaluate the capabilities of crewmen, physiological cost of the activities, dynamic stability of the structures, effectiveness of the equipment and procedures, and areas of procedures, equipment, and crew skill which merit revision.

D. 1-OE-4 Module Operations

Module operations include (1) deployment and retrieval of modules, (2) rendezvous and docking, (3) manned operations in maintaining, resupplying, and reconfiguring modules, and (4) remote monitoring and control of module operations, subsystem status, and attitude. Data collection for a particular free-flying module begins with initial launch, rendezvous, and docking to the spacecraft, and continues during the first three to six months of its operation. Data from operational instrumentation, TV monitoring, and crew subjective comments will be used to obtain crew tasks times and errors, metabolic cost, quality of displayed data, responses of module systems, and evaluation of equipment, procedures, and crew skills.

E. 1-OE-5 Vehicle Support Operations

The support services of interest are Medical Services, Food Management, Data Management, Power Management, Vehicle Control, and Communications. Conduct of these operations will be evaluated using the following items: crew logs; responses to questionnaires; time lines of crew activities; and TV film records to obtain data on individual crew times, total time required to provide services, frequency with which service is required, time delays in providing services, availability of equipment when needed, and adequacy of equipment and procedures.

4. Impact on Spacecraft

Hardware impact of Operations Experiments on the spacecraft is negligible since operational equipment will be used and the observation and measurement equipment is provided by other research clusters. Use of this measurement equipment will impose a power impact of approximately 200 watts average.

This research cluster will impose on the spacecraft Data Management and Communications Subsystems an additional load of data handling, the magnitude of which cannot be ascertained until operational program schedules are firm.

5. Required Supporting Technology Development

The major ground effort required is carefully conducted and controlled ground experiments, using the best available simulation facilities to refine techniques and equipment for the operations with which this research cluster is concerned.

To accommodate the extensive extravehicular activity (EVA) described in the research clusters of this subdiscipline, major ground-based supporting research and technology is required in high fidelity simulation and development of aids for extravehicular operations (egress/ingress, translation, work performance) and in the development and test of life support systems (space suits, food and waste management, portable life support systems).

3.3 SCREENING AND GROUPING OF CRITICAL ISSUES IN SPACE BIOLOGY

The critical issues in Space Biology were derived on the basis of identifying the parameters critical to the growth and survival of living organisms in any environment. They were determined initially by highlighting the characteristics that distinguish living from non-living things. They are presented below.

Life is dependent upon the coupled chemical processes of metabolism. All forms of life require a means of deriving energy from their environment, are capable of reproducing themselves, responding to various stimuli in a consistent manner, and possess a well defined and organized structure.

Each of these five general characteristics were then subdivided into increasingly more specific subareas directly involved in the processes that collectively describe life. The issues were evolved by asking questions of the form: "What is the influence of the environment upon a specific functional process in a representative form of life?" This type of question can be utilized to derive a research program on the effect of any environment on life processes.

3.3.1 Screening for Space Research Applicability

As long as the NASA goals and objectives include man in space, the need for continued research in Space Biology will continue. Additional facts describing man's physiological response to space flight factors will always be needed. In Space Biology, as with earth-based biology, advances in knowledge are gained through experimentation and observation. In cases where direct experimentation on man would compromise the well-being of the subject, the presumptive physiological data can usually be obtained by studying laboratory animals.

The issues were screened for relevance to research in space by restricting the environmental factors considered to those that are characteristic of space (Chart 2-1, Appendix A). These space-related environment factors are confined, to weightlessness and the interaction of weightlessness with other environmental factors. It should be noted that the number of issues was not affected by this procedure. These questions are the critical issues, that must ultimately be answered before life can be functionally characterized.

The number of critical issues was not altered by applying a filter of space applicability. The careful selection of experiments and biological specimens for space research is important because the payload, power, and other space vehicle resources required for their growth and maintenance in orbit are available only in limited quantities. Smaller animals require less power and less of the other vehicle resources than do large animals. Thus, when larger numbers of small animals can be studied, the statistical and inferential value of the experiments will be increased.

It has also been noted that in a single, carefully planned experiment, several critical issues can frequently be answered as efficiently and economically as one. Therefore, it is important to select specimens that permit the largest number of critical issues to be examined. Size may not be the critical factor here; structural and functional characteristics are the dominating factors.

In summary, the number of critical issues requiring study is not influenced through applying space research applicability as a filter. Rather, the way in which the issues are studied is the principal factor that is influenced.

3.3.2 Screening for Manned Space Research Applicability

3.3.2.1 Selection Factors

The determination of which biological research should be carried out in orbit onboard manned (as distinguished from automated) space platforms was based upon what man contributes to the experiment and whether the presence of man increases the number of critical issues that can be examined. However, applicability-to-man considerations did not influence the number of critical issues requiring answers. Nor are the number of critical issues reduced by the presence of man. On the contrary, the number of measurable issues will actually be greater as a result of man's availability to assist in the conduct of the experiments, through sample preparation, and analysis processes.

The limiting factor in biological experimentation is the ingenuity to ask significant questions and devising appropriate experiments to answer the questions. Instrumentation limits the parameters which can be measured. Categorically the number of critical issues that can be answered in an automated biological experiment is equipment capability limited.

3.2.2.2 Manned Constraints Peculiar to Biology

Developing valid biological experiments requires, among other factors, adequate provisions for maintaining the living specimens. Moreover, it is important to maintain them in an environment that is similar to the normal terrestrial environment in as many respects as possible. The space environment contributes sufficient uniqueness (weightlessness, etc.) to constitute, of itself, the basis for the experimentation. To complicate the research program through additional alterations in the environment, such as variation from the terrestrial norms would only lead to costly additional experimentation to unravel the effects of spacecraft factors from those of space flight factors. If an environmental difference must be maintained between mans living area and the experimental area then man must make the transition between the two rather than the experimental material.

Another requirement is a constant level of hypogravity. The level most often quoted is 10^{-5} for 90 percent of the mission. This level was specified and essentially achieved in the Biosatellite program. If man's presence interferes with this requirement, it may be possible through isolation design, "soft-tethering, restriction of movement or relaxation of the requirement to support the research requirement for a hypogravity." In any event an early determination of the threshold and a time-dependency threshold should be established.

A third biology-peculiar requirement is the isolation of the test specimens from the waste products of all other life onboard the space research facility. Waste products of animal life can act as fertilizers and influence the growth characteristics of plants. Consideration of this factor is most important for the evaluation of the growth processes in plants. This problem is not restricted to liquid and solid wastes, since gaseous wastes can also cause profound physiological responses in plants. Ammonia and carbon dioxide are but two examples of gaseous waste that can be utilized by plants for growth, ammonia providing nitrogen and carbon dioxide providing carbon.

Finally, it should be recognized that living things carry diseases that could be transmitted to an experimenter. Although the chance of man's health and performance being compromised by biological experiments does exist in a small percentage of the experiments contemplated, proven prophylactic measures are available that make any dangers from this source extremely remote. Well-trained experimental scientists or astronaut-technicians should be able to conduct the biological experimentation with negligible risk to both crew and mission.

3.3.3 Contributions of Ongoing Programs

3.3.3.1 Ongoing Programs Considered

180 NASA-supported biology research programs were reviewed. The majority of this activity is being conducted at universities and colleges, a lesser portion is being carried out at NASA research centers, and a few programs are being conducted within the industrial complex. Each program was analyzed for its potential contribution to Space Biology.

Each program was categorized by area of research so that an overall picture could be formulated of the emphasis placed on the various aspects of Space Biology research. This distribution is shown in Table 3-7. It may be seen that a large proportion of the research programs (79 out of 180) involve metabolic processes, and that the other 101 programs are more or less evenly distributed among animal behavior, genetic mechanisms, cellular structure and organization, biorhythmic processes, geosensitivity and tropisms, reproduction and development, and host-parasite relationships. The large number of programs concerned with metabolism is to be expected since metabolic processes cannot be easily separated from other basic biological processes. For this reason, some of the programs listed in the metabolism category also contribute in related categories, such as genetics or cellular structure and organization.

Table 3-7

AREAS OF NASA-SUPPORTED BIOLOGY RESEARCH

Research Area	No. of Programs
Metabolic Processes	79
Animal Behavior	22
Genetic Mechanisms	18
Cellular Structure and Organization	17
Biorhythmic Processes	16
Geosensitivity and Tropisms	11
Reproduction and Development	9
Host-Parasite Relationships	8
Total	180

3.3.3.2 Critical Issues Answered

These research programs are to improve the understanding of biological processes. This knowledge is necessary for continuing investigation of biology, whether in space or on earth. Since the investigations in ground-based laboratories are being performed in a 1-g environment, none of the critical Space Biology issues will be directly addressed. These ground-based programs are a base with which the biology research in space could be correlated. Thus, all critical issues in Space Biology were retained, since the basic research being conducted in the ongoing programs applies only to baseline data for future investigations in zero gravity.

Clustering of Critical Issues into Experiment Groups

In exploring the clustering criteria for the critical issues, it became apparent that clustering around common analytical instrumentation requirements was a functional organization. It also became apparent that a large number of additional critical issues could be accommodated through the addition of a modest number of instruments. It can be seen that planning an earth-orbiting laboratory is similar to planning a ground-based laboratory in the sense that, for either one, a complement of instruments can be carefully chosen to satisfy almost all analytical requirements. Beyond this, supplemental instrumentation will add little to the capability of the facility.

Several critical issues can be examined in a single biological specimen. Clustering can occur on this basis. For example, the same specimen that is used to demonstrate how a plant is morphologically or visibly affected by weightlessness can be sectioned and analyzed for investigation of a number of critical issues in the areas of metabolism, energetics, reproduction, and organization.

Both of these commonality factors-instrumentation and test specimens-were exploited as described below in the procedure used for grouping critical issues into research clusters.

3.3.4.1 Grouping by Instrumentation

In common analytical instrumentation grouping, the issues within each life process area were used, for convenience, as the initial groups. The equipment requirement analyses for each of these groups are shown in Tables 3-8 through 3-12. The type of analytical and preparative instrumentation is specified for each critical issue, and the preferences among available methods for data acquisition are indicated. The instrument requirement is also related to program development in these tables.

The basis for sequencing biology research in space rests on the logic that general phenomena should be investigated initially, followed by experimentation into those components of the phenomenon that in the initial investigation indicate alterations were the result of the space environment. Lastly, detailed examinations should be made of the mechanisms responsible for the observed changes. This logic is also embraced in the related Biotechnology Laboratory Requirements Study.*

*NASA-CR 111794-2, Phase II of a Requirements Study for Manned Earth-Orbiting Mission, Sept. 1970.

Table 3-8

EQUIPMENT REQUIREMENTS AND EXPERIMENT PROGRAM PHASE FOR CRITICAL ISSUES IN METABOLISM (2. 1. 1) BRANCH OF SPACE BIOLOGY

Critical Issue		Analytical Instrumentation, Equipment and Materials to Fulfill Information Requirements: Recording Spectro-photometer	Isotope Tracer Techniques	Manometer Measurement of CO_2 Evolution	Bio-assay	Preparative Instrumentation, Equipment, and Materials: Homog-enizor	Chromo-tographic	Electro-phoresis	Centri-fuge	Dialy-ser	Incu-bator	Phase of Experi-ment Program
2. 1. 1. 1 Anabolism												
2. 1. 1. 1. 1 Energy Storage Elements												
2. 1. 1. 1. 1. 1 Carbohydrate	2. 1. 1. 1. 1. 1. 1 Starch	2	1			X	X		X			Advanced*
	2. 1. 1. 1. 1. 1. 2 Fructosans	2	1			X	X		X			Advanced*
	2. 1. 1. 1. 1. 1. 3 Mannans	2	1			X	X		X			Advanced*
	2. 1. 1. 1. 1. 1. 4 Glycogen	2	1			X	X		X			Advanced*
	2. 1. 1. 1. 1. 1. 5 Dextran	2	1			X	X		X			Advanced*
	2. 1. 1. 1. 1. 1. 6 Inulin	2	1			X	X		X			Advanced*
	2. 1. 1. 1. 1. 1. 7 Other Polysaccharides	2	1			X	X		X			Advanced*
2. 1. 1. 1. 1. 2 Protein Energy Storage Elements	2. 1. 1. 1. 1. 2. 1 Creatine Phosphate	2	1			X	X	X	X			Advanced*
2. 1. 1. 1. 1. 3 Lipid Energy Storage Elements	2. 1. 1. 1. 1. 3. 1 Acetyle Co-A		1			X	X	X	X			Advanced*
2. 1. 1. 1. 2. 1 Carbohydrate Structural Elements	2. 1. 1. 1. 2. 1. 1 Chitin	2	1			X	X		X			Advanced*
	2. 1. 1. 1. 2. 1. 2 Cellulose	2	1			X	X		X			Advanced*
	2. 1. 1. 1. 2. 1. 3 Xylan	2	1			X	X		X			Advanced*
	2. 1. 1. 1. 2. 1. 4 Arabinose	2	1			X	X		X			Advanced*
	2. 1. 1. 1. 2. 1. 5 Mannose	2	1			X	X		X			Advanced*
	2. 1. 1. 1. 2. 1. 6 Lignin	2	1			X	X		X			Advanced*
	2. 1. 1. 1. 2. 1. 7 Other Polysaccharides	2	1			X	X		X			Advanced*
2. 1. 1. 1. 2. 2 Mineral Structural Elements	2. 1. 1. 1. 2. 2. 1 Skeletal											
	2. 1. 1. 1. 2. 2. 1. 1 Calcium	2	1			X	X		X	X		Advanced*
	2. 1. 1. 1. 2. 2. 1. 2 Phosphorus	2	1			X	X		X	X		Advanced*
	2. 1. 1. 1. 2. 2. 1. 3 Others	2	1			X	X		X	X		Advanced*
	2. 1. 1. 1. 2. 2. 2 Nonskeletal Minerals											
	2. 1. 1. 1. 2. 2. 2. 1 Sodium	2	1			X	X		X	X		Advanced*
	2. 1. 1. 1. 2. 2. 2. 2 Potassium	2	1			X	X		X	X		Advanced*
	2. 1. 1. 1. 2. 2. 2. 3 Chloride	2	1			X	X		X	X		Advanced*
	2. 1. 1. 1. 2. 2. 2. 4 Others	2	1			X	X		X	X		Advanced*
2. 1. 1. 1. 2. 3 Protein Structural Elements	2. 1. 1. 1. 2. 3. 1 Muscle Proteins; 2. 1. 1. 1. 2. 3. 2 Collagen; 2. 1. 1. 1. 2. 3. 3 Other Proteins		1			X	X	X	X	X		Advanced
2. 1. 1. 1. 3 Regulatory Elements												
2. 1. 1. 1. 3. 1 Hormones	2. 1. 1. 1. 3. 1. 1 Plant											
	2. 1. 1. 1. 3. 1. 1. 1 Auxins		1		2	X	X		X		X	Advanced*
	2. 1. 1. 1. 3. 1. 1. 2 Kinetins		1		2	X	X		X		X	Advanced*
	2. 1. 1. 1. 3. 1. 1. 3 Gibberellins		1		2	X	X		X		X	Advanced*
	2. 1. 1. 1. 3. 1. 2 Animal											
	2. 1. 1. 1. 3. 1. 2. 1 Thyroid	1	2		3	X	X		X		X	Advanced*
	2. 1. 1. 1. 3. 1. 2. 2 Parathyroid	3	2		1	X	X		X		X	Advanced*
	2. 1. 1. 1. 3. 1. 2. 3 Gonadal	3	2		1	X	X		X		X	Advanced*
	2. 1. 1. 1. 3. 1. 2. 4 Adrenal Cortical	3	2		1	X	X		X		X	Advanced*
	2. 1. 1. 1. 3. 1. 2. 5 Adrenal Medulla	3	2		1	X	X		X		X	Advanced*
	2. 1. 1. 1. 3. 1. 2. 6 Pancreatic	3	2		1	X	X	X	X		X	Advanced*
	2. 1. 1. 1. 3. 1. 2. 7 Other	3	2		1	X	X		X		X	Advanced*
2. 1. 1. 1. 3. 2 Genetic Materials	2. 1. 1. 1. 3. 2. 1. 1 Anabolism of Nucleotides											
	2. 1. 1. 1. 3. 2. 1. 1. 1 ATP	2	1			X	X	X	X	X		Advanced*
	2. 1. 1. 1. 3. 2. 1. 1. 2 UTP	2	1			X	X	X	X	X		Advanced*
	2. 1. 1. 1. 3. 2. 1. 1. 3 GTP	2	1			X	X	X	X	X		Advanced*
	2. 1. 1. 1. 3. 2. 1. 1. 4 Others	2	1			X	X	X	X	X		Advanced*
	2. 1. 1. 1. 3. 2. 1. 2 DNA	2	1			X	X	X	X			Advanced*
	2. 1. 1. 1. 3. 2. 1. 3 RNA's											
	2. 1. 1. 1. 3. 2. 1. 3. 1 mRNA	2	1			X	X		X			Advanced*
	2. 1. 1. 1. 3. 2. 1. 3. 2 +RNA	2	1			X	X		X			Advanced*
	2. 1. 1. 1. 3. 2. 1. 3. 3 rRNA	2	1			X	X		X			Advanced*
	2. 1. 1. 1. 3. 2. 1. 3. 4 Others	2	1			X	X		X			Advanced*
	2. 1. 1. 1. 3. 2. 2 Histones	-	1			X	X		X	X		Advanced*
2. 1. 1. 1. 3. 3 Enzyme Cofactors	2. 1. 1. 1. 3. 3. 1 Coenzyme A	3	1		2	X	X	X	X	X	X	Advanced*
	2. 1. 1. 1. 3. 3. 2 Flavins	3	1		2	X	X	X	X	X	X	Advanced*
	2. 1. 1. 1. 3. 3. 3 Biotin	3	1		2	X	X	X	X	X	X	Advanced*
	2. 1. 1. 1. 3. 3. 4 Nicotinic Acid	3	1		2	X	X	X	X	X	X	Advanced*
	2. 1. 1. 1. 3. 3. 5 Folic Acid	3	1		2	X	X	X	X	X	X	Advanced*
	2. 1. 1. 1. 3. 3. 6 Cobamide Coenzyme	3	1		2	X	X	X	X	X	X	Advanced*
	2. 1. 1. 1. 3. 3. 7 Thiamine Cocarboxylase	3	1		2	X	X	X	X	X	X	Advanced*
	2. 1. 1. 1. 3. 3. 8 Others	3	1		2	X	X	X	X	X	X	Advanced*
2. 1. 1. 2 Control Mechanisms of Metabolism												
2. 1. 1. 2. 1 Hormonal												
2. 1. 1. 2. 1. 1 Plants	2. 1. 1. 2. 1. 1. 1 Auxins		2		1	X	X		X		X	Advanced*
	2. 1. 1. 2. 1. 1. 2 Kinetins		2		1	X	X		X		X	Advanced*
	2. 1. 1. 2. 1. 1. 3 Gibberelins		2		1	X	X		X		X	Advanced*
2. 1. 1. 2. 1. 2 Animal	2. 1. 1. 2. 1. 2. 1 Thyroid	3	2		1	X	X		X		X	Advanced*
	2. 1. 1. 2. 1. 2. 2 Parathyroid	3	2		1	X	X		X		X	Advanced*
	2. 1. 1. 2. 1. 2. 3 Gonadal	3	2		1	X	X		X		X	Advanced*
	2. 1. 1. 2. 1. 2. 4 Adrenal Cortical	3	2		1	X	X		X		X	Advanced*
	2. 1. 1. 2. 1. 2. 5 Adrenal Medulla	3	2		1	X	X		X		X	Advanced*
	2. 1. 1. 2. 1. 2. 6 Pancreatic	3	2		1	X	X	X	X		X	Advanced*
	2. 1. 1. 2. 1. 2. 7 Others	3	2		1	X	X		X		X	Advanced*
2. 1. 1. 2. 2 Genetic												
2. 1. 1. 2. 2. 1 Positive Feedback		2	1			X	X	X	X	X	X	Advanced*
2. 1. 1. 2. 2. 2 Negative Feedback		2	1			X	X	X	X	X	X	Advanced*
2. 1. 1. 2. 2. 3 *Inborn Errors in Metabolism*		2	1			X	X	X	X	X	X	Advanced*
2. 1. 1. 3 Catabolism												
2. 1. 1. 3. 1 Polynucleotide Breakdown												
2. 1. 1. 3. 1. 1 Nucleotide Breakdown	2. 1. 1. 3. 1. 1. 1 ATP	2	1									Intermed
	2. 1. 1. 3. 1. 1. 2 UTP	2	1									Intermed
	2. 1. 1. 3. 1. 1. 3 ITP	2	1									Intermed
	2. 1. 1. 3. 1. 1. 4 GTP	2	1									
2. 1. 1. 3. 1. 2 Nucleoside Breakdown	2. 1. 1. 3. 1. 2. 1 Adenosine	2	1			X	X	X	X		X	Advanced*
	2. 1. 1. 3. 1. 2. 2 Cytidine	2	1			X	X	X	X		X	Advanced*
	2. 1. 1. 3. 1. 2. 3 Inosine	2	1			X	X	X	X		X	Advanced*
	2. 1. 1. 3. 1. 2. 4 Guanosine	2	1			X	X	X	X		X	Advanced*
2. 1. 1. 3. 1. 3 Catabolism of Bases	2. 1. 1. 3. 1. 3. 1 Catabolism of Purines											
	2. 1. 1. 3. 1. 3. 1. 1 Adenine	2	1			X	X	X	X		X	Advanced*
	2. 1. 1. 3. 1. 3. 1. 2 Hypoxanthine	2	1			X	X	X	X		X	Advanced*
	2. 1. 1. 3. 1. 3. 1. 3 Xanthine	2	1			X	X	X	X		X	Advanced*
	2. 1. 1. 3. 1. 3. 1. 4 Thianine	2	1			X	X	X	X		X	Advanced*
	2. 1. 1. 3. 1. 3. 2 Catabolism of Pyrimidines											
	2. 1. 1. 3. 1. 3. 2. 1 Uracil	2	1			X	X	X	X		X	Advanced*
	2. 1. 1. 3. 1. 3. 2. 2 Cytosine	2	1			X	X	X	X		X	Advanced*
	2. 1. 1. 3. 1. 3. 2. 3 Thymine	2	1			X	X	X	X		X	Advanced*
2. 1. 1. 3. 1. 4 Catabolism of Sugars	2. 1. 1. 3. 1. 4. 1 Ribose	2	1			X	X		X		X	Advanced*
	2. 1. 1. 3. 1. 4. 2 Deoxyribose	2	1			X	X		X		X	Advanced*
2. 1. 1. 3. 2 Catabolism of Proteins												
2. 1. 1. 3. 2. 1 Glycogenic Processes		2	1			X	X		X		X	Advanced*
2. 1. 1. 3. 2. 2 Amino Acid Pools		2	1			X	X		X		X	Advanced*
2. 1. 1. 3. 2. 3 Ketogenic Processes		2	1			X	X		X		X	Advanced*
2. 1. 1. 3. 3 Catabolism of Lipids												
2. 1. 1. 3. 3. 1 Catabolism of Fatty Acids	2. 1. 1. 3. 3. 1. 1 Beta-Oxidation	2	1			X	X		X		X	Advanced*
	2. 1. 1. 3. 3. 1. 2 Omega-Oxidation	2	1			X	X		X		X	Advanced*
2. 1. 1. 3. 3. 2 Triglycerides												
2. 1. 1. 3. 4 Catabolism of Carbohydrates												
2. 1. 1. 3. 4. 1 Aerobic Carbohydrate Catabolism	2. 1. 1. 3. 4. 1. 1 Pentrose Phosphate Shunt	3	1	2		X	X		X		X	Advanced*
	2. 1. 1. 3. 4. 1. 2 TCA Cycle	3	1	2		X	X		X		X	Advanced*
2. 1. 1. 3. 4. 2 Anaerobic Carbohydrate Metabolisms	2. 1. 1. 3. 4. 2. 1 Glycolytic Mechanisms	3	1	2		X	X		X		X	Advanced*
	2. 1. 1. 3. 4. 2. 2 Nonglycolytic Mechanisms	3	1	2		X	X		X		X	Advanced*

Note: Numbers indicate order of preference.

*Can be investigated initially in the intermediate phase by analyzing crude tissue homogenates spectrophotometrically.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Table 3-9

EQUIPMENT REQUIREMENTS AND EXPERIMENT PROGRAM PHASE FOR CRITICAL ISSUES IN ENERGETICS (2. 1. 2) BRANCH OF SPACE BIOLOGY

Critical Issue			Analytical Instrumentation, Equipment, and Materials to Fulfill Information Requirements			Preparative Instrumentation, Equipment, and Materials					Phase of Experiment Program
			Recording Spectro-photometer	Isotope Tracer Techniques	Manometer Measurement of CO_2 Evolution	Homogeni-zor	Chromato-graphic	Electro-phoretic	Centri-fuge	Dialyzer	
2.1.2.1 Nonphotophosphorylation	2.1.2.1.1. Aerobic Mechanisms										
	2.1.2.1.1.1 TCA Cycle	2.1.2.1.1.1.1 Pyruvic Oxidase	1	2	3	X	X		X		Advanced*
		2.1.2.1.1.1.2 Isocitric Enzyme	1	2		X	X		X		Advanced*
		2.1.2.1.1.1.3 α - Ketoglutarate Oxidase	1	2	3	X	X		X		Advanced*
		2.1.2.1.1.1.4 Succinyl Thiokinase		1		X	X		X		Advanced*
		2.1.2.1.1.1.5 Succinic Acid Dehydrogenase		1		X	X		X		Advanced*
		2.1.2.1.1.1.6 Malic Acid Dehydrogenase	1	2		X	X		X		Advanced*
	2.1.2.1.1.2 Cytochrome System	2.1.2.1.1.2.1 NAD/FAD Crossover Point		1		X	X		X		Advanced*
		2.1.2.1.1.2.2 FAD/Cytochrome C Crossover Point		1		X	X		X		Advanced*
		2.1.2.1.1.2.3 Cytochromec/ Cytochrome Oxidase Crossover Point		1		X	X		X		Advanced*
	2.1.2.1.1.3 Pentose Phosphate Shunt	2.1.2.1.1.3.1 Glucose-6-Phosphate Dehydrogenase	1	2		X	X		X		Advanced*
		2.1.2.1.1.3.2 6-Phosphogluconic Acid Dehydrogenase	1	2	3	X	X		X		Advanced*
	2.1.2.1.1.4 Lipid Metabolism	2.1.2.1.1.4.1 Acyl Dehydrogenase		1		X	X		X		Advanced*
		2.1.2.1.1.4.2 Hydroxylacyl Dehydrogenase	1	2		X	X		X		Advanced*
	2.1.2.1.1.5 Oxidative Deamination	2.1.2.1.1.5.1 Glutamic Acid Dehydrogenase	1	2		X	X		X		Advanced*
		2.1.2.1.1.5.2 D-Amino Acid Oxidase		1		X	X		X		Advanced*
	2.1.2.1.1.6 Transamination	2.1.2.1.1.6.1 Transaminases	1	2		X	X		X		Advanced*
	2.1.2.1.2 Anaerobic Mechanisms										
	2.1.2.1.2.1 Glycolysis	2.1.2.1.2.1.1 Phosphogly Ceraldehyde Dehydrogenase	1	2		X	X		X		Advanced*
		2.1.2.1.2.1.2 Phosphoglyceryl Kinase		1		X	X		X		Advanced*
		2.1.2.1.2.1.3 Pyruvic Oxidase		1		X	X		X		Advanced*
	2.1.2.1.2.2 Nonglycolytic Mechanisms	2.1.2.1.2.2.1 Nitrate Reductase		1		X	X		X	X	Advanced*
		2.1.2.1.2.2.2 Sulfate Reductase		1		X	X		X	X	Advanced*
2.1.2.2 Photophosphanylation	2.1.2.2.1 Chemolithotropic Reactions										
	2.1.2.2.1.1 Transhydro-genase (Ferridoxin/ NAD(P) Reductase		1			X	X	X	X		Advanced*
	2.1.2.2.1.2 Chlorophyll		1			X	X	X	X		Advanced*
	2.1.2.2.2 Photolithotropic Reactions										
	2.1.2.2.2.1 Oxidation of Fe^{++} to Fe_2O_3			1		X	X		X	X	Advanced*
	2.1.2.2.2.2 Oxidation of Thiosulfate to Sulfate			1		X	X		X	X	Advanced*

Note: Numbers indicate order of preference.

*Can be investigated initially in the intermediate phase by analyzing crude tissue homogenates spectrophotometrically.

FOLDOUT FRAME

Table 3-9

EQUIPMENT REQUIREMENTS AND EXPERIMENT PROGRAM PHASE
FOR CRITICAL ISSUES IN ENERGETICS (2. 1. 2)
BRANCH OF SPACE BIOLOGY

Critical Issue	Analytical Instrumentation, Equipment, and Materials to Fulfill Information Requirements			Preparative Instrumentation, Equipment, and Materials					Phase of Experiment Program
	Recording Spectro-photometer	Isotope Tracer Techniques	Manometer Measurement of CO_2 Evolution	Homogeni-zor	Chromato-graphic	Electro-phoretic	Centri-fuge	Dialyzer	

Table 3-10

EQUIPMENT REQUIREMENTS AND EXPERIMENT PROGRAM PHASE FOR CRITICAL ISSUES IN RESPONSES TO STIMULI (2. 1. 3) BRANCH OF SPACE BIOLOGY

	Critical Issue	Analytical Instrumentation, Equipment, and Materials to Fulfill Information Requirements							Phase of Experiment Program
		Observation (Camera, Microscopes, etc)	Potentiometers	Manometer (Measurement of CO_2 Evolution)	Chromatographic	Recording Spectrophotometer	Isotope Traces Techniques	Flow Rate Monitors	
2.1.3.1 Tropisms	2.1.3.1.1 Geotropic Response	1							Preliminary
	2.1.3.1.2 Phototropic Response	1							Preliminary
	2.1.3.1.3 Thermotropic Response	1							Preliminary
	2.1.3.1.4 Hydrotropic Response	1							Preliminary
	2.1.3.1.5 Chemotropic Response	1							Preliminary
	2.1.3.1.6 Tropic Interactions	1	1	1	1	1	1		Advanced*
2.1.3.2 Rhythms	2.1.3.2.1 Circadian Rhythms								
	2.1.3.2.1.1 Organism Activity	1							Preliminary
	2.1.3.2.1.2 Feeding	1							Preliminary
	2.1.3.2.1.3 Flower and Leak Movements	1							Preliminary
	2.1.3.2.1.4 Organic Acid Metabolism	1							Preliminary
	2.1.3.2.1.5 Phototaxis		Refer to Metabolism and Energetics Sections						
	2.1.3.2.1.6 Rate of Photosynthesis	1							Preliminary
	2.1.3.2.1.7 Gonyualax Rhythms		1	2	4		3		Preliminary
	2.1.3.2.1.8 Cell Division	1	2	3			4		Preliminary
	2.1.3.2.1.9 Root Exudation	1					2		Preliminary
	2.1.3.2.1.10 Discharge	1							Preliminary
	2.1.3.2.1.11 Oestrum Odor Production	1							Preliminary
	2.1.3.2.1.12 Excretion of Urinary Constituents	2			1				Advanced
	2.1.3.2.2 Tidal Rhythms								
	2.1.3.2.2.1 Pumping Rate of Mussels						2	1	Intermediate
	2.1.3.2.2.2 Amphipod Emergence from Sand	1							Preliminary
	2.1.3.2.2.3 Flatworm Emergence from Sand	1							Preliminary
	2.1.3.2.2.4 Fucus Respiration Rate		1	2			3		Preliminary
	2.1.3.2.2.5 Crab Respiratory O_2 Intake		1	2					Preliminary
	2.1.3.2.2.6 Amphipod Navigation	1							Preliminary
	2.1.3.2.2.7 Crab Activity	1							Preliminary
	2.1.3.2.2.8 Crab Color Changes	1							Preliminary
	2.1.3.2.2.9 Diatom Migration to Mud Surface	1							Preliminary
	2.1.3.2.3 Semilunar Rhythms								
	2.1.3.2.3.1 Marine Algae Spore and Gamete Liberation	1							Preliminary
	2.1.3.2.4 Lunar Rhythms								
	2.1.3.2.4.1 Palolo Worm Spawning	1							
	2.1.3.2.5 Annual Rhythms								
	2.1.3.2.5.1 Photoperiodism								
	2.1.3.2.5.2 Hibernation	1	1	3			2		Preliminary
	2.1.3.2.5.3 Reproduction	1				1	2		Preliminary
	2.1.3.2.5.4 Seed Germination	1							Preliminary
2.1.3.2 Rhythms (Cont'd)	2.1.3.2.5.5 Nitrate Reduction Capacity					1			Intermediate
	2.1.3.2.5.6 Growth Rate of Plants	1							Preliminary
	2.1.3.2.6 Rhythms Independent of Environmental Periodicities								
	2.1.3.2.6.1 Beating of Flagella and Cilia	1							Preliminary
	2.1.3.2.6.2 Leaf Movements	1							Preliminary
	2.1.3.2.6.3 Protoplasmic Movement in Slime Mold	1							Preliminary
	2.1.3.2.6.4 Stomatal Openings	1							Preliminary
	2.1.3.2.6.5 Root Tip Potentials		1						Preliminary
	2.1.3.2.6.6 Shoot, Root, Tendril Growth	1							Preliminary
	2.1.3.2.6.7 Flowering of Bamboo	1							Preliminary
	2.1.3.2.6.8 Glycolytic Enzyme Oscillations					1	2		Preliminary

Note: Numbers indicate order of preference.

*Can be investigated initially in the intermediate phase by analyzing crude tissue homogenates spectrophotometrically.

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Table 3-11

EQUIPMENT REQUIREMENTS AND EXPERIMENT PROGRAM PHASE FOR CRITICAL ISSUES IN REPRODUCTION (2. 1. 4) BRANCH OF SPACE BIOLOGY

Critical Issue			Analytical Instrumentation Equipment, and Materials to Fulfill Information Requirements: Observation (Cameras, Microscopes, etc)	Isotope Tracer Techniques	Recording Spectrophotometer	Bacterial Genetic Materials	Preparative Instrumentation, Equipment, and Materials: Autoclave	Microtome and Paraffin Oven	Incubator	Chromatographic	Electrophoresis	Centrifuge	Phase of Experiment Program
2.1.4.1 Development	2.1.4.1.1 Sexual												
	2.1.4.1.1.1 Animals	2.1.4.1.1.1.1 Fertilization	1										Preliminary
		2.1.4.1.1.1.2 Cleavage	1										Preliminary
		2.1.4.1.1.1.3 Differentiation	1										Preliminary
		2.1.4.1.1.1.3.1 Ectoderm Derivatives	1										Preliminary
		2.1.4.1.1.1.3.1.1 Ectoderm	1					X	X				Intermediate
		2.1.4.1.1.1.3.1.2 Presumptive Epidermis	1					X	X				Intermediate
		2.1.4.1.1.1.3.1.3 Neural Plate	1					X	X				Intermediate
		2.1.4.1.1.1.3.1.4 Advanced Ectodermal Derivatives	1					X	X				Intermediate
		2.1.4.1.1.1.3.2 Mesoderms and Derivatives											
		2.1.4.1.1.1.3.2.1 Mesoderm	1					X	X				Intermediate
		2.1.4.1.1.1.3.2.2 Chorda	1					X	X				Intermediate
		2.1.4.1.1.1.3.2.3 Somites	1					X	X				Intermediate
		2.1.4.1.1.1.3.2.4 Nephrotome	1					X	X				Intermediate
		2.1.4.1.1.1.3.2.5 Lateral Plate	1					X	X				Intermediate
		2.1.4.1.1.1.3.2.6 Advanced Mesodermal Derivatives	1					X	X				Intermediate
		2.1.4.1.1.1.3.3 Endoderm and Derivatives											
		2.1.4.1.1.1.3.3.1 Endoderm	1					X	X				Intermediate
		2.1.4.1.1.1.3.3.2 Advanced Endodermal Derivatives	1					X	X				Intermediate
	2.1.4.1.1.2 Plants	2.1.4.1.1.2.1 Isogametes	1					X					Intermediate
		2.1.4.1.1.2.2 Heterogametes											
		2.1.4.1.1.2.2.1 Antheridium	1					X					Intermediate
		2.1.4.1.1.2.2.2 Oogonium	1					X					Intermediate
	2.1.4.1.2 Asexual												
	2.1.4.1.2.1 Motile Sponophytes		1					X	X				Intermediate
	2.1.4.1.2.2 Nonmotile Sponophytes		1					X	X				Intermediate
2.1.4.2 Genetics	2.1.4.2.1 Replication												
	2.1.4.2.1.1 Lethal Mutations		1					X					Intermediate
	2.1.4.2.1.2 Conditional Lethal, Mutations		1					X					Intermediate
	2.1.4.2.1.3 Nonlethal Mutations	2.1.4.2.1.3.1 Structural	1					X					Intermediate
		2.1.4.2.1.3.2 Biochemical		1	2				X	X	X	X	Advanced
		2.1.4.2.1.3.3 Chromosomal	1								X	X	Advanced
	2.1.4.2.2 Information Exhanges												
	2.1.4.2.2.1 Sexual Processes	2.1.4.2.2.1.1 Sexduction		2		1	X					X	Intermediate
		2.1.4.2.2.1.2 Conjugation		2		1	X					X	Intermediate
	2.1.4.2.2.2 Epigenetic			2		1	X					X	Intermediate
	[illegible] Abnormal Processes	[illegible] Transduction		2		1	X					X	Intermediate
		[illegible] Transformation		2		1	X					X	Intermediate
	2.1.4.2.3 Information Storage												
	2.1.4.2.3.1 Information Storage in DNA	2.1.4.2.3.1.1 Induction		1					X	X	X	X	Advanced
		2.1.4.2.3.1.2 Repression		1					X	X	X	X	Advanced
	2.1.4.2.3.2 RNA			1					X	X	X	X	Advanced
		2.1.4.2.3.2.1 Enzyme Synthesis		1					X	X	X	X	Advanced
		2.1.4.2.3.2.2 Nucleotide Synthesis		1					X	X	X	X	Advanced

Note: Numbers indicate order of preference.

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Table 3-12 (Page 1 of 3)

EQUIPMENT REQUIREMENTS AND EXPERIMENT PROGRAM PHASE FOR CRITICAL ISSUES IN ORGANIZATION (2, 1, 5) BRANCH OF SPACE BIOLOGY

			Analytical Instrumentation, Equipment, and Materials to Fulfill Information Requirements															Preparative Instrumentation, Equipment, and Materials									
		Critical Issue	Observation (Cameras, Microscopes, Etc.)	Potentiometers	Flow Rate Monitor	Pressure Transducer	Stimulation and Ablation	Strain Gage	Thermistor	Respiratory Gas Monitor	Isotope Tracer Techniques	Spectrophotometer	Chromatographic	Manometer (Measurement of CO_2 Evolution)	Bioassay	Immunochemical Methods	Electrophoresis	Animal Care	Surgical	Histological Instruments	Incubator	Centrifuge	Homogenizator	Chromatographic	Electrophoresis	Dialysis	Phase of Experiment Program
2.1.5.1 Physiological	2.1.5.1.1 Nervous System	2.1.5.1.1.1.1 Sensory Nerves																									
		2.1.5.1.1.1.1.1 Exteroceptive		1			2											X	X								Preliminary
		2.1.5.1.1.1.1.2 Interoceptive		1			2											X	X								Preliminary
		2.1.5.1.1.1.1.3 Proprioceptive		1			2											X	X								Preliminary
		2.1.5.1.1.1.2 Effector Nerves																									
		2.1.5.1.1.1.2.1 Neuromotor		1			3	2										X	X								Preliminary
		2.1.5.1.1.1.2.2 Sympathetic		2			1											X	X								Intermediate
		2.1.5.1.1.1.2.3 Parasympathetic		2			1											X	X								Intermediate
		2.1.5.1.1.1.2.4 Secretory	3	2			1											X	X								Intermediate
		2.1.5.1.1.2.1 Spinal Nerves																									
		2.1.5.1.1.2.1.1 Reflexes		1			2	3										X	X								Preliminary
		2.1.5.1.1.2.1.2 Conduction		1			2	3										X	X								Preliminary
		2.1.5.1.1.2.1.3 Facilitation and Inhibition		1			2											X	X								Preliminary
		2.1.5.1.1.2.2 Brain																									
		2.1.5.1.1.2.2.1 Motor Control Centers	4	1			2	3										X	X								Preliminary
		2.1.5.1.1.2.2.2 Visceral Control Centers	3	1			2											X	X								Preliminary
		2.1.5.1.1.2.2.3 Centers Associated with Learning	3	1			2											X	X								Preliminary
		2.1.5.1.1.2.2.4 Centers Associated with Memory	3	1			2											X	X								Preliminary
		2.1.5.1.1.2.2.5 Centers Associated with Emotion	3	1			2											X	X								Preliminary
	2.1.5.1.2 Musclo-Skeletal System	2.1.5.1.2.1.1.1 Striated Muscles																									
		2.1.5.1.2.1.1.1.1 Locomotion Muscles		2			3	1										X	X								Preliminary
		2.1.5.1.2.1.1.1.2 Support Muscles		2			3	1										X	X								Preliminary
		2.1.5.1.2.1.1.1.3 Respiratory Muscles					2			3								X									Preliminary
		2.1.5.1.2.1.1.1.4 Muscles Associated with Organs	4	3			2	1										X									Preliminary
		2.1.5.1.2.1.1.2.1 Involuntary Striated Muscles	4	3			2	1										X									Preliminary
		2.1.5.1.2.1.2.1.1 Cardiac Muscle		1	4	3	5	2										X	X								Preliminary
		2.1.5.1.2.1.2.1.2 Respiratory Muscles	1				2			3								X									Preliminary
		2.1.5.1.2.1 2.1.3 Muscles Associated/Temp Reg	2						1									X			X						Preliminary
		2.1.5.1.2.1.2.2 Non-Striated Involuntary Muscles																									
		2.1.5.1.2.1.2.2.1 Dermal	1				2											X									Preliminary
		2.1.5.1.2.1.2.2.2 Vascular	-				2	1										X									Preliminary
		2.1.5.1.2.1.2.2.3 Respiratory	1				2											X									Preliminary
		2.1.5.1.2.1.2.2.4 Sphincteric	2					1										X									Preliminary
		2.1.5.1.2.1.2.2.5 Gastrointestinal	2					1										X									Preliminary
		2.1.5.1.2.1.2.2.6 Urogenital	2					1										X									Preliminary
		2.1.5.1.2.1.2.2.7 Reticuloendothelial	2				1				3							X									Intermediate
		2.1.5.1.2.1.2.2.8 Glandular	2				1											X									Intermediate
		2.1.5.1.2.2.1 Locomotion																									
		2.1.5.1.2.2.1.1 Musculoskeletal Attachments	1															X	X								Preliminary
		2.1.5.1.2.2.1.2 Skeletal Articulation	1															X	X								Preliminary
		2.1.5.1.2.2.2 Protection																									
		2.1.5.1.2.2.2.1 Of Specific Organs	1				2											X	X								Preliminary
		2.1.5.1.2.2.2.2 Of General Body Areas	1				2											X	X								Preliminary
		2.1.5.1.2.2.3 Skeletal Support																									
		2.1.5.1.2.2.3.1 To External Stress					1											X	X								Intermediate
		2.1.5.1.2.2.3.2 To Internal Stress					1											X	X								Intermediate
		2.1.5.1.2.2.3.3 To Body Shape					1											X	X								Intermediate
	2.1.5.1.3 Vascular System	2.1.5.1.3.1 Transport Processes									1	2	3					X			X	X		X			Advanced
		2.1.5.1.3.1.1 Organic Nutrients									1	2						X			X	X				X	Intermediate
		2.1.5.1.3.1.2 Inorganic Nutrients																									
		2.1.5.1.3.1.3.1 Respiratory Pigments									3	1					2	X				X					Intermediate
		2.1.5.1.3.1.3.2 Gas Solubility									1	2	3					X			X	X		X			Advanced
		2.1.5.1.3.1.4 Organic Waste Products									1	2						X				X				X	Intermediate
		2.1.5.1.3.1.5 Inorganic Waste Products									1		3		2			X				X		X			Advanced
		2.1.5.1.3.1.6 Hormones																									
		2.1.5.1.3.2.1 Internal Homeostatic Processes																									
		2.1.5.1.3.2.1.1 Regulatory Mechanisms		2			1											X	X								Intermediate
		2.1.5.1.3.2.1.2 Cardiodynamics		3	2	1	5	4										X	X								Preliminary
		2.1.5.1.3.2.1.3 Hemodynamics	3		1	2												X	X								Preliminary
		2.1.5.1.3.2.1.4 Osmotic Pressure				1					2															X	Preliminary
		2.1.5.1.3.2.1.5 Active Transport Processes		1							2	3									X						Preliminary
		2.1.5.1.3.2.2 Extracellular Fluids									1	2						X	X			X				X	Intermediate
		2.1.5.1.3.2.3 Extracellular Electrolytes									1	2						X	X			X					Intermediate
		2.1.5.1.3.2.4 Acid Base Balance																									
		2.1.5.1.3.2.4.1 CO_2 Regulation		1							2			3	4			X				X					Intermediate
		2.1.5.1.3.2.4.2 Respiratory Exchange										1			2			X				X					Intermediate
		2.1.5.1.3.2.5 Heat Exchange Capacity																									
		2.1.5.1.3.2.5.1 Conversion Process			1				2		3							X	X								Preliminary
		2.1.5.1.3.2.5.2 Respiratory Exchange								1	2							X									Preliminary
		2.5.5.1.3.2.5.3 Dermal Exchange			1				2		3							X	X								Preliminary
	2.1.5.1.4 Organ Systems	2.1.5.1.4 Organ Systems																									
		2.1.5.1.4.1.1.1 Endocrine Hormones									2	4	3		1			X			X	X	X	X			Advanced
		2.1.5.1.4.1.2 Exocrine Systems																									
		2.1.5.1.4.1.2.1 Enzyme Systems									1	2						X			X	X	X		X		Advanced
		2.1.5.1.4.1.2.2 Lubricants									1	2						X									Intermediate
		2.1.5.1.4.1.2.3 Heat Exchange Capacity		2							1							X									Intermediate
		2.1.5.1.4.2 Gastrointestinal System																									
		2.1.5.1.4.2.1 Digestion of Nutrients									1							X				X		X			Advanced
		2.1.5.1.4.2.2 Absorption									1							X				X		X			Advanced
		2.1.5.1.4.3 Hepatic Organs																									
		2.1.5.1.4.3.1 Metabolism									1	2						X			X	X	X	X			Advanced
		2.1.5.1.4.3.2 Detoxification									1	2						X			X	X	X	X			Advanced
		2.1.5.1.4.3.3 Storage Processes									1	2						X		X	X	X		X			Advanced
		2.1.5.1.4.4 Hemopoietic Organs																									
		2.1.5.1.4.4.1 Production of Formed Elements	2								1	3						X		X		X	X				Intermediate
		2.1.5.1.4.4.2 Storage Capacity	2								1	3						X		X		X	X				Intermediate
		2.1.5.1.4.5 Reticuloendothelial Organs																									
		2.1.5.1.4.5.1 Immune Mechanism									2					1		X		X	X	X			X		Advanced
		2.1.5.1.4.5.2 Removal of Foreign Elements	2								1							X		X							Advanced
		2.1.5.1.4.5.3 Formed Elements																									
		2.1.5.1.4.5.3.1 Production	2								1							X		X		X					Intermediate
		2.1.5.1.4.5.3.2 Removal	2								1							X		X							Intermediate
		2.1.5.1.4.6 Renal Organs																									
		2.1.5.1.4.6.1 Waste Product Removal									1	2						X				X					Intermediate
		2.1.5.1.4.6.2 Acid Base Balance		2							1	3						X				X					Intermediate
		2.1.5.1.4.6.3 Conservation of Electrolytes									1	2						X								X	Intermediate
		2.1.5.1.4.6.4 Conservation of H_2O	2								1							X								X	Intermediate
		2.1.5.1.4.7 Reproductive Organs																									
		2.1.5.1.4.7.1 Oogenesis	1								2							X		X							Intermediate
		2.1.5.1.4.7.2 Spermatogenesis	1								2							X		X							Intermediate

Note: Numbers indicate order of preference

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Table 3-12 (Page 2 of 3)

EQUIPMENT REQUIREMENTS AND EXPERIMENT PROGRAM PHASE FOR CRITICAL ISSUES IN ORGANIZATION (2, 1, 5) BRANCH OF SPACE BIOLOGY

Area	Critical Issue		Observation	Audiometer and Response Board (Primate)	Audio-Visual Tactile Stimulator (Primate)	Light Discrimination Apparatus and Response Board (Primate)	Flicker Fusion Apparatus (Primate)	Multi-Choice Stimulus Display (Primate)	Tach is to Score Response Board (Primate)	Pseudo-Isochromatic Plates (Primate)	Activity Platform (Small Animal)	Visual Cuff (Small Animal)	Animal Maze - Modular Test Units (Small Animal)	GSR (Primate)	EKG (Primate)	EEG (Primate)	EMG (Primate)	Respiration Rate (Primate)	Reaction Time (Primate)	Phase of Experiment Program
2.1.5.2 Behavioral	**2.1.5.2.1 Sensation**																			
	2.1.5.2.1.1 Cutaneous Sensation		1		1															Preliminary
	2.1.5.2.1.2 Audition		2	1																Preliminary
	2.1.5.2.1.3 Taste		1																	Preliminary
	2.1.5.2.1.4 Olfactory		1																	Preliminary
	2.1.5.2.1.5 Vision																			Preliminary
		2.1.5.2.1.5.1 Brightness				2	1													Preliminary
		2.1.5.2.1.5.2 Acuity																		Preliminary
		2.1.5.2.1.5.3 Spatial					1						1							Preliminary
		2.1.5.2.1.5.4 Temporal					1													Preliminary
		2.1.5.2.1.5.5 Motion					1													Preliminary
	2.1.5.2.2 Perception																			
	2.1.5.2.2.1 Visual Form																			Preliminary
	2.1.5.2.2.2 Color	2.1.5.2.2.2.1 Contrast							2	1										Preliminary
		2.1.5.2.2.2.2 Field							2	1										Preliminary
		2.1.5.2.2.2.3 Adaptation							2	1										Preliminary
	2.1.5.2.2.3 Depth											1								Preliminary
	2.1.5.2.2.4 Time			1									1							Preliminary
	2.1.5.2.2.5 Sound			1									1							Preliminary
	2.1.5.2.3 Individual and Group Learning												1							Preliminary
	2.1.5.2.3.1 Conditioning					1							1							Preliminary
	2.1.5.2.3.2 Discrimination					2		1												Preliminary
	2.1.5.2.3.3 Maze Design												1							Preliminary
	2.1.5.2.3.4 Shifts and Span of Attention							2	1											Preliminary
	2.1.5.2.3.5 Association							2	1											Preliminary
	2.1.5.2.3.6 Set Effects							2	1											Preliminary
	2.1.5.2.3.7 Transfer							2	1											Preliminary
	2.1.5.2.3.8 Reasoning							1												Preliminary
	2.1.5.2.4 Memory																			
	2.1.5.2.4.1 Interference								1											Preliminary
	2.1.5.2.4.2 Recall								1											Preliminary
	2.1.5.2.4.3 Recognition								1											Preliminary
	2.1.5.2.4.4 Retention								1											Preliminary
	2.1.5.2.5 Individual and Group Motivation								1				1							Preliminary
	2.1.5.2.5.1 Drives												1						1	Preliminary
	2.1.5.2.5.2 Prime. and Sec Incentives												1						1	Preliminary
	2.1.5.2.5.3 Nonorganic Drives												1						1	Preliminary
	2.1.5.2.5.4 Learning												1						1	Preliminary
	2.1.5.2.6 Emotion and Stress																		1	Preliminary
	2.1.5.2.6.1 Neural Activation		2								1		2							Preliminary
		2.1.5.2.6.1.1 Central Nervous System	2				1				1		2	1	1	1	1	1		Preliminary
		2.1.5.2.6.1.2 Sympathetic and Parasympathetic Nervous System	2								1		2	1	1	1	1	1		Preliminary
	2.1.5.2.6.2 Other Bodily Changes		2								1		2	1	1	1	1	1		Preliminary
		2.1.5.2.6.2.1 Circulation	2								1		2	1	1	1	1	1		Preliminary
		2.1.5.2.6.2.2 Muscular Tension	2								1		2	1	1	1	1	1		Preliminary
		2.1.5.2.6.2.3 Respiration	2											1	1	1	1	1		Preliminary
	2.1.5.2.6.3 Expressive Movements	2.1.5.2.6.3.1 Facial	1																	Preliminary
		2.1.5.2.6.3.2 Voice	1																	Preliminary

Note: a. Numbers indicate order of preference.

b. No preparative instrumentation required for these measurements.

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Table 3-12 (Page 3 of 3)

EQUIPMENT REQUIREMENTS AND EXPERIMENT PROGRAM PHASE FOR CRITICAL ISSUES IN ORGANIZATION (2. 1. 5) BRANCH OF SPACE BIOLOGY

2.1.5.3 Host-Parasite Relationships

	Analytical Instrumentation Equipment and Materials to Fulfill Information Requirements													Preparative Instrumentation Equipment, and Materials										
Critical Issue	Aerosolizer	Aerosol Sampler	Immunochemical Techniques	Biochemical Conversion	Microscopic Observations	Aerosol Size Estimator	Spectrophotometer	Electrophoresis	Chronometer	Isotope Tracer Techniques	Mass Spectrometer	Gas Chromatograph	Electron Spin Resonance	Animal Colony	Histological Instruments	Incubator	Centrifuge	Sterilizer	Freezer	Water Bath	Microscope	Quarantine Facility	Washer	Phase of Experiment Program
2. 1. 5. 3. 1 Disease Transmission																								
2. 1. 5. 3. 1. 1. 1 Aerosol Physical Stability	1	1				1				2											X			Intermediate
2. 1. 5. 3. 1. 1. 1. 2 Aerosol Rate of Dissemination	1	1							1					X		X		X			X	X	X	Intermediate
2. 1. 5. 3. 1. 1. 1. 3 Aerosol Longevity	1	1				1								X		X		X			X	X	X	Intermediate
2. 1. 5. 3. 1. 1. 1. 4 Microbe Viability	1	1	2	1										X		X		X			X	X	X	Intermediate
2. 1. 5. 3. 1. 1. 2. 1 Penetration Pattern	1	1								1	2	2	2	X	X									Intermediate
2. 1. 5. 3. 1. 1. 2. 2 Microbe Lodgement	1	1	1	1	1	1				2				X	X	X	X	X	X	X	X	X	X	Intermediate
2. 1. 5. 3. 1. 1. 2. 3. 1 Disease Transmission	1	1	1	1	1									X	X	X	X	X	X	X	X	X	X	Intermediate
2. 1. 5. 3. 1. 1. 2. 3. 2 Resistance	1	1	1	2	1									X	X	X		X	X		X	X	X	Intermediate
2. 1. 5. 3. 1. 1. 2. 3. 3 Confined Space Transmission	1	1	2	1	1					2				X	X	X	X	X	X		X	X	X	Intermediate
2. 1. 5. 3. 1. 1. 2. 3. 4 Number of Microbes Released		1	1	1	2									X	X	X	X	X	X		X	X	X	Intermediate
2. 1. 5. 3. 1. 1. 2. 3. 5 Aerosol Type						1				1		1												Intermediate
2. 1. 5. 3. 1. 1. 2. 3. 6 Course of Infection			1	2	1									X	X	X	X	X			X	X	X	Intermediate
2. 1. 5. 3. 2 Normal Flora																								
2. 1. 5. 3. 2. 1. 1 Quantitative Alterations				1										X	X	X					X		X	Intermediate
2. 1. 5. 3. 2. 1. 2 Qualitative Alterations		1		1	1									X	X									Intermediate
2. 1. 5. 3. 2. 1. 3 Selective Factors			1	1									1	X	X						X	X		Advanced
2. 1. 5. 3. 2. 1. 4 Protective Functions					1									X	X	X	X				X	X		Intermediate
2. 1. 5. 3. 2. 2 Repopulation			1	2	1																			Intermediate
2. 1. 5. 3. 3 Immune Response																								
2. 1. 5. 3. 3. 1. 1 Response to Vaccines			1	1										X	X									Intermediate
2. 1. 5. 3. 3. 1. 2 Response to Other Antigens			1	1									2							X	X			Intermediate
2. 1. 5. 3. 3. 2 Immune Globulin A			2					1					2	X						X	X			Advanced
2. 1. 5. 3. 3. 3 Thymus Function			2				1	1						X										Advanced
2. 1. 5. 3. 3. 4 Lymphocyte Transformation					1									X	X									Advanced
2. 1. 5. 3. 3. 5 Immune Globulin Synthesis								1						X										Advanced
2. 1. 5. 3. 3. 6 Macrophage Antigen Processing			1		2			1						X	X									Advanced
2. 1. 5. 3. 3. 7. 1 Microbial Shock			1	1	2		2	2						X	X		X							Intermediate
2. 1. 5. 3. 3. 7. 2 Long-Term Susceptibility			1	1	2																			Advanced
2. 1. 5. 3. 3. 8. 1 Mucociliary Function					1																			Advanced
2. 1. 5. 3. 3. 8. 2 Phagocytic Clearance					1																			Advanced
2. 1. 5. 3. 3. 8. 3 Lysozyme Concentration			1			1								X	X									Intermediate
2. 1. 5. 3. 3. 8. 4 [illegible]										1				X	X									Advanced
2. 1. 5. 3. 4 Latent Infections																								
2. 1. 5. 3. 4. 1 Host Defenses			1		1									X			X							Advanced
2. 1. 5. 3. 4. 2 Latent Infections			1		1									X			X							Advanced

Notes: Numbers indicate order of preference. All analytical and preparative instrumentation listed in requirements for vertebrates and protists will be required to supplement the requirements stated above.

The initial, or preliminary, phase in this sequence would involve minimal manned participation in orbit, employing automated observation and preservation for post-flight analysis. The intermediate phase would involve increased in-orbit demands upon the experimenters' time and ability. The advanced phase would require active, full-time engagement of scientists and technicians in orbit. More in-space analysis would be conducted as the intermediate and advanced phases were undertaken. In Table 3-13 instrumentation types are categorized according to these three phases.

Ground-based research will augment all inflight activities. Planning of ground-based research should be incorporated into space research facility forecasting because of the intimate coordination required between the two types of activities. Less obviously, instrumentation should be included in the space research facility that will allow accurate real-time simulation of environmental and experimental perturbations, so that proper controls may be provided on earth. Only a cursory analysis of the related ground-based research is included in the research cluster descriptions. The descriptions emphasize research in-space.

Table 3-13 (Page 1 of 2)

SPACE BIOLOGY RESEARCH INSTRUMENTATION

PRELIMINARY PHASE INSTRUMENTATION

Observational Equipment

- Cameras
  - Time-lapse
  - Motion picture
  - Still

  } With microscopic and normal lenses

- Microscopes
  - Tissue culture
  - Compound
  - Dissecting

Preservation Equipment

- Refrigerator
- Freezer
- Liquid nitrogen storage
- Specimen containers
- Chemical preservatives

Table 3-13 (Page 2 of 2)

SPACE BIOLOGY RESEARCH INSTRUMENTATION

Other Equipment

Sterilizer
Strain gauges
Implanted flow probes, electrodes, and transducers
Incubator
Surgical tools
Dissecting kit
Mass spectrometer
Potentiometers
Animal maze modular behavior test unit
Primate behavioral test unit

INTERMEDIATE PHASE INSTRUMENTATION

(All of the preliminary phase instrumentation, plus the following)

Analytical Instruments and Materials

Amino acid analyzer
Spectrophotometer
Radioisotopic tracer equipment
Manometers
Centrifuge
Bioassay materials
Gas chromatograph

Preparative Equipment

Homogenizers
Dialysis equipment
Microtome and paraffin oven
Histology kit

ADVANCED PHASE INSTRUMENTATION

(All of the intermediate phase instrumentation, plus the following)

Analytical Equipment

Immunochemistry materials and equipment
Ultracentrifuge

Preparative Equipment

Electrophoretic equipment
Chromatography equipment

3.3.4.2 Grouping by Biological Specimen

Most experimental organisms have unique life support requirements, experiment regimens and have a reservoir of accumulated knowledge; these form the basis of organizing the critical issues around an experimental organism. A rationale for selecting four principle groups of biological specimens was extensively discussed in the Biotechnology Laboratory Study cited earlier. (See Table 3-14). Furthermore, a universal theory for biological processes is being sought, comparative experiments for many critical issues should be performed on a variety of biological forms and also a variety of types within a given form. The research clusters are addressed to groups of critical issues sharing not only common instrumentation requirements but also common types of biological specimens. This relationship is shown schematically in Figure 3-20. The 12 research clusters derived in this way are described in detail in Appendix C.

3.3.5 Alternative Experimental Approaches in Space Biology

Alternative analytical methods and alternative choices of biological specimens were considered to minimize the instrumentation requirements and experimental material. The decision to select a particular analytical approach was usually based upon simplicity of operation, safety, confidence in the resultant data and amenability to spacecraft systems. Similarly, the selection of the biological specimens was based on the number of critical issues that could be answered rapidly, with minimal preparation, and with minimum impact on the housekeeping requirements of the earth-orbiting laboratory. The prediction of optimum equipment requirements was facilitated by this approach.

3.3.6 Brief Descriptions of the Space Biology Research Clusters

In summary, 12 research clusters were formed from the critical issues judged to be suitable for a manned earth-orbital research program. These 12 research clusters correspond to the four principal types of biological specimens--vertebrates, invertebrates, protists and tissue cultures, and plants--each represented by a preliminary, an intermediate, and an advanced phase of research. A brief description of these research clusters is presented below. More detailed descriptions are given in Appendix C.

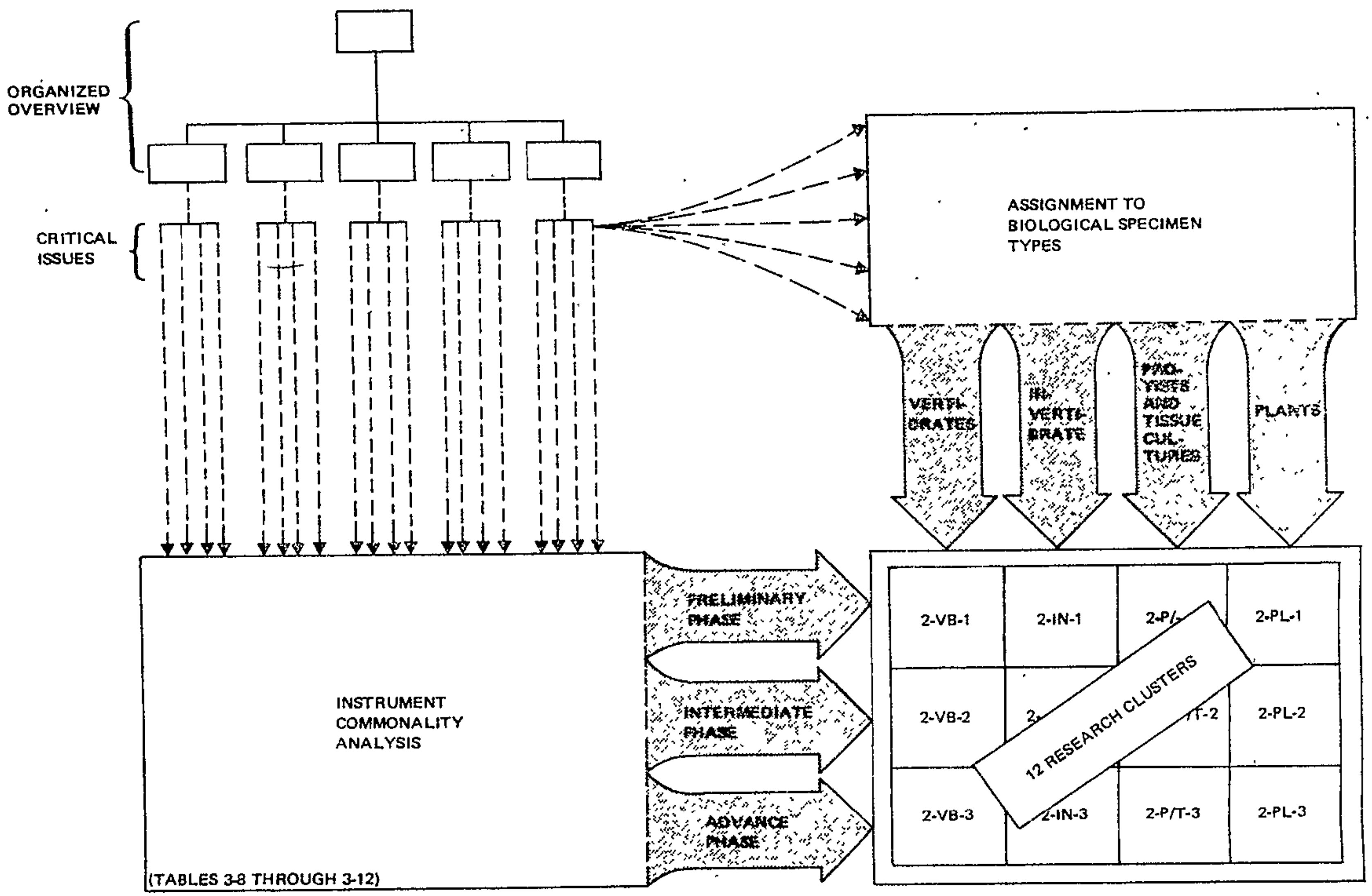

Figure 3-20. Clustering of Space Biology Critical Issues into Experiment Groups

Table 3-14

BIOLOGICAL SPECIMEN GROUPS FOR EXPERIMENT CLUSTERING

Vertebrates	Protists and Tissue Cultures
Mice	Bacteria
Rats	Viruses
Marmots	Tissue cultures
Monkeys	Bread mold (Neurospora)
Invertebrates	**Plants**
Fruit fly (Drosophila)	Marigold
Beetles	Wheat
Cockroaches	Small fern (Pteris)
House flies	Bean
Fiddler crabs	Arabidopsis
Spiders	
Parasite wasps (Habrobracon)	

DISCIPLINE SYNOPSIS

Space Biology

1. Research Objectives

A number of life processes in various members of all living kingdoms appear to be influenced and directed by the earth's gravitational field and by earth-lunar cyclical cues. It is impossible to eliminate all of these influences in terrestrial experiments. Consequently, their role in the activities of the organism cannot be defined with precision. The space environment offers a unique situation in which to observe biological processes in the absence of gravity and normal cyclic cues. Introduction of additional controlled independent variables into the experiment, the interaction between gravity or earth-lunar cycles and such factors as radiation, temperature, and light-dark cycles may be ascertained. In this manner, space biology research has the opportunity of contributing to the development of a coherent, universal theory for biology and of bringing a new dimension to the study of life.

In the Space Biology research program three broad objectives are defined:

1. To understand the role of gravity in life processes and the capability of living organisms to adapt to gravitational changes.
2. To understand the rate of adaptation in biological systems, including the effects of time-varying environmental parameters on biological rhythms and aging.
3. To determine the potential applications and develop techniques of utilizing new biological advances in theory and space technology, thus advancing biology, medicine, agriculture, and space exploration.

The third of these objectives was considered to be too "future oriented" and too predominantly derived from experimental results to be of significance in generating requirements for Space Biology laboratories. This objective was not studied in expanded form.

In addition, subordinate objectives associated with the various life processes were derived from suggestions of outside consultants, study groups and advisors. These were classified under the headings, metabolism, energetics, responses to stimuli, reproduction, and organization.

In the analysis of the Space Biology objectives a three-dimensional matrix was constructed (shown in Appendix A) for which the above life processes formed one axis; a second axis was devoted to taxonomy (the subdivisions of the three biological kingdoms-animals, plants and protists); the third axis was composed of environmental parameters which influence the life processes.

Critical issues were generated by matrix intersections, with the greatest emphasis placed on the life processes matrix. The taxonomy matrix served to indicate the proper specimen to illustrate a particular process and the environment axis was restricted to gravity and earth-lunar cyclical cues for the purposes of this research program. A total of 324 critical issues were established.

2. Background and Current Status

Ground-based simulations of weightlessness have not generally been successful for investigating gravity-dependent functions in animals or protists. For plants, however, the clinostat has been successful in depriving specimens of their gravity orientation and thereby producing changes in their development, physiology, and tropistic responses.

Early suborbital and short orbital spaceflights carried biological experiments onboard. Invertebrates predominated as experimental subjects in these flights. Most experiments were secondary to the testing of the launch vehicle and produced very little usable data.

The first space program designed specifically for research in space was the Biosatellite program. The flight of Biosatellite II in 1967 carried onboard *Drosophila*, *Tribolium*, *Habrobracon*, wheat seedlings, pepper plants, *Neurospora crassa*, lysongenic bacteria, frog eggs, and the amoeba, *Pelomysa carolinensis*, from which much information was derived. Investigations were made of the interaction of the space environment and radiation on both reproductive cell damage and somatic damage in *Drosophila*, the effect of irradiation in space on the flour beetle, and the nutritional response of *Habrobracon*. The pepper plants and wheat seedlings exhibitied morphological responses similar to those elicited by the clinostat; and, in addition, an indication of physiological abberations was observed in the wheat seedling. The observed characteristics of the frog eggs and amoeba remained essentially unchanged in the space environment. The bacteria multiplied more rapidly in weightlessness; however, it remains controversial as to whether this increase in growth rate is the result of more rapid anabolic reactions or simply better dispersion of the bacteria in the fluid media. A circadian rhythm in growth and spore discharge is observed in the "clock" mutant of *Neurospora*; it is not known whether the timing mechanism is of terrestrial or endogenous origin. Additional information of biological interest in anticipated from the experiments scheduled for Skylab A which will include: S015 Zero Gravity Single Human Cells, S061 Potato Respiration, and S071 and S072 Circadian Rhythm in Pocket Mice and Vinegar Gnats (*Drosophila*). Successful completion of these experiments will significantly increase the body of knowledge of the effects of the space environment on life processes; much, however, will remain to be done. These experimental results must be verified and will certainly suggest additional avenues of investigation. There also remains an enormous number of suggested experiments of great value which have not yet been accommodated on any of the defined space programs.

3. Description of Research

For the purpose of experimental design, research clusters based on specimen commonality rather than process commonality appeared to be the most feasible. Consequently, four major groupings were established for the four major specimen categories-protists and tissue cultures, vertebrates, invertebrates, and plants.

The sequencing of experiments was based both on experimental design and expediency. Quite appropriate is the common scientific approach of initial general observations being followed by more complete examination of those aspects showing alteration, and is concluded in detailed studies of mechanisms. The recognition of the limitations of crew size, available time, and specialized skills in early space flight leads to the design of experiments which, at first, require minimal crew involvement; next, moderate involvement; and, later, extensive crew involvement. These two approaches are readily combined in program definition.

As a consequence of these considerations, three phases were established for each specimen-oriented cluster: Phase I, investigating general processes and requiring minimal astronaut participation; Phase II, investigating previously observed changes and requiring increased astronaut participation; and Phase III, investigating the mechanisms responsible for the changes, requiring sophisticated techniques and extensive astronaut participation.

In the Phase I clusters of the four research areas, experiments requiring individual, automated, self-contained, experimental modules predominate. These include an experimental mouse module and automated primate laboratory in the vertebrate area; modules for the study of Drosophila behavior, housefly aging, tidal rhythm color changes in fiddler crabs and beetle embryogenesis in the invertebrate area; modules for the study of Arabidopsis plant growth and development, cucumber lignification, and verification of potato respiratory rhythm in the plant research area; and experimental modules for Neurospora, frog egg fertilization and single human cells. In addition some bacterial growth and morphological studies will be performed which will involve selective media and culture preparation, culture plating, and bacterial genetic techniques. Crew activities associated with a daily general inspection of the animals, the removal and preservation of dead or dying subjects, and the preparation of the subjects for reentry and return will comprise the major activities supporting the module experiments. Some relatively simple crew tasks such as plant harvesting and replanting, specimen counting, and the discrimination of morphological abnormalities and sex characteristics will be required by a few of the experiments.

Phase II is characterized by a significant increase in crew activities associated primarily with laboratory analyses. Required for the experiments in this category are the establishment of an onboard biochemistry chemistry laboratory and laboratories for microbiological work, tissue preparation, and small-animal surgery for histopathological examinations. Some members of the crew should have significant training and experience in these laboratory activities with assistance from cross-trained crewmen.

Phase III experiments will be directed toward the investigation of mechanisms, through the use of sensitive measurement systems and astronaut experiment manipulation. Specific physiological and structural changes cannot yet be predicted; no specific experiments can be assumed for the determination of mechanisms. Regardless, the experiments will undoubtedly involve studies at the subcellular level including investigations of metabolic pathways and transport mechanisms. Activities will include (1) the isolation of enzymes, (2) the reaction of tagged substrate with the enzyme system (the substrate would be tagged with a radioactive or heavy or light isotope tracer before flight), and (3) the determination of enzyme activity by the measurement of isotope disappearance from the substrate or its appearance in the products of the reaction. Such studies require advanced instrumentation, complex and precise techniques, and fully experienced technicians. It would be desirable for the principal investigator to be onboard for the conduct of the experiments. Acting as a substitute in his absence, should be highly qualified, experienced technologists. The duties of the team should be essentially restricted to space biology research.

4. Impact on Space Stations

The major impact of Phase I experiments will come from the experimental modules which are expected to be essentially self-contained with their own environmental control systems, waste management systems, food and water dispensers, TV cameras, and recording electronics. The individual modules will vary extensively in their impact; the Drosophila module is expected to weigh 40 lb, occupy 2 cu ft, and require an average of 30 watts of power for a 24-hour period; the primate module is expected to weigh 900 lb, occupy 110 cu ft, and require an average 80 watts of power plus 30w during video recording. Modules for the other suggested Phase I experiments fall somewhere between these two requirement extremes.

Phase II research will continue to require self-contained modules for the experimental subjects, the number required is dependent on the number of experiments that can be accommodated on a specific mission. In addition, certain laboratory facilities will be required. Blood and urine may be analyzed in the biochemical laboratory; a single microbiology laboratory serving various ship's functions will suffice for the required microbiological analyses; but animal dissection, autopsy, and histopathological examinations will require space and facilities not required by other experimental disciplines. These will include an automatic tissue processor and staining system, vacuum infiltration oven, microtome, and compound microscope with built-in automatic camera. Added for plant and animal tissue preparation for biochemical studies should be a refrigerated centrifuge, homogenizer, dialysis equipment, and an incubation facility.

The major item of additional equipment will be the onboard biocentrifuge, for which no design requirements have yet been specified; it is, however, expected to approach the human centrifuge in its capabilities with a much more continuous running time. Its purpose would be to create an artificial gravity equivalent to the earth's unit gravity; it would not, therefore, be required to produce high g forces or high angular velocities. At an anticipated radius of 10 to 12 feet, rotational rates of 16-18 RPM would be required. The weight of the centrifuge would probably be near 1000 lb and occupy about 550 cu ft.

Phase III experiments will continue to include modules for experimental subjects although the requirements for modular self-containment will be significantly reduced. Laboratory requirements will be increased to include facilities capable of permitting enzyme isolation, measuring cellular metabolism, and studying membrane phenomena and transport systems.

.5. Required Supporting Technology Development

The development, design, construction, and testing of the experimental modules is the major task in preparation for Phase I experiments. A number of subsystems must be designed and integrated for the proper overall functioning of the module. Some of this work is already in progress at various NASA centers. Information derived from the design of the Biosatellite II modules will be of value in designing future modules. The major requirement for Phase II experiments will be the design and construction of the biocentrifuge; although no major studies are in progress on this item of equipment, much of the information generated in the NASA-General Dynamics Human Centrifuge Study will be applicable. Some of the general laboratory equipment required for Phase II studies is conceived for development in the IMBLMS program, the major exception being the equipment and procedures required for specimen preparation and storage. Required for these items are development, testing, and integration. Phase III requirements are almost totally in the area of SRT. Conceptual studies must be undertaken in all cases to properly integrate the laboratories in the overall space vehicle design.

3.4 SCREENING AND GROUPING OF CRITICAL ISSUES IN SPACE ASTRONOMY

The selection from among the Space Astronomy critical issues (Table 3 of Appendix B) of those that warrant inclusion in a manned earth orbital research program followed this three-step screening process:

1. Identification of critical issues requiring earth-orbital observations, as opposed to those addressable through ground-based, suborbital, or in situ observations.
2. Selection of those "earth-orbital critical issues" (Item 1, above) which will involve manned observations or man-supported instruments.
3. Elimination of the "manned critical issues" (Item 2, above) which are answerable by currently scheduled or planned orbital missions.

3.4.1 Screening for Earth Orbital Research Applicability

The factors weighed in identifying earth orbital critical issues are summarized in Table 3-15. Tables 3-16 and 3-17 give additional details concerning atmospheric transmission and vehicles, respectively, which could not be adequately presented in Table 3-15. Because of the variety of available vehicles or platforms for astronomical observations, it was not possible to base this critical issue selection on any single criterion. Illustrating this point is the fact that earth satellites, which have much greater access to the electromagnetic spectrum than do ground observatories, must share this advantage with sounding rockets. The rockets, however, have inferior observing times and payloads. Indeed, in this selection phase, in order to reflect the valuable experience and judgment of other experimenters to date, considerable weight was given to recognizing the types of observations that have made use of the vehicles or platforms under consideration.

In addition, consideration was given to alternative ground-based instrumental capabilities in connection with some observations that appeared to be advantageously done from orbit. For example, by means of phase and intensity interferometry it is possible to measure stellar angular diameters which are $\sim 10^3$ smaller than a typical stellar "seeing disc," or $\sim 10^2$ times smaller than the diffraction discs produced by the larger existing telescopes.* It has not been clearly demonstrated that the instruments involved in this type of work would perform significantly better in earth orbit. Also, a number of techniques are

*The "seeing" phenomenon is included in Table 3-15 in the "sky noise" category, which can also refer to fluctuating atmospheric emission.

Table 3-15

FACTORS CONSIDERED IN SELECTION OF EARTH ORBITAL CRITICAL ISSUES IN ASTRONOMY

Operating Altitudes	Vehicles or Platforms	Atmospheric: Transparency	Atmospheric: Emission or Scattering	Continuous Observing Time	Instrument Payload	Miscellaneous
5 to 13,000 ft	Ground	Good $>10^4$ MeV Good 0.4 - 0.7μ Fair 0.7 - 24μ Fair 0.7 - 10 mm Good 1 cm - 30 m	Airglow, sky noise Man-made interference	To ≈ 12 hr	No limit due to platform	Interference by poor weather
35 to 50,000 ft	Aircraft	Good 0.4 - 30μ Fair 30 - 700μ Good 0.7 mm - 30 m	Airglow	2 to 5 hr	0.2 to 5 tons	Can select optimum observing locations for some events
15 to 21 mi	Balloons	Good >0.1 MeV Good 0.3μ - 30 m	Atmosphere-background intense 0.1 to 10^4 MeV Airglow 0.3 - 30μ	To ≈ 12 hr	1 to 2 tons	Platform lifetime limited to ≈ 30 days
50 to 260 mi	Sounding rockets	Good >0.1 keV Fair 100 - 1000 Å* Good 1000Å - 60 m	Residual airglow Residual airglow 0.1 to 0.7μ	5 to 9 min	To 300 lb	Also 30 to 60 m (LF radio) interference during solar activity
200 to 10,000 mi	Earth satellites	Good <60 m	Residual airglow 0.1 to 0.7μ 200 mi altitude	1 to 8 hr	200 to 6,000 lb**	LF interference during solar activity
10,000 to 20,000 mi	Earth satellites	Good $< 10^4$ m†		8 to 24 hr	200 to 6,000 lb**	Higher orbits possible

NOTES:

*Interstellar hydrogen absorbs most XUV radiation from outside the solar system.

†Interplanetary plasma blocks radiation of wavelengths $>10^4$ m (<0.03 MHz).

**Much heavier payloads possible for assembled stations.

Table 3-16

ATMOSPHERIC EFFECTS ON ELECTROMAGNETIC RADIATION FROM ASTRONOMICAL SOURCES

Wavelength/ Energy Range Name	Energies or Wavelengths	Transmission; Penetration Level	Emission; Scattering; Fluctuations of Background
Gamma rays	10^4 Mev	Penetrates to ground	---
	0.1 to 10^4 Mev	Penetrates to 15 to 20 mi altitude	Intense below 20 mi altitude
X-rays	0.2 to 20 kev (60 to 0.6 Å)	Penetrates to 50 to 100 mi altitude	---
XUV (extreme ultraviolet)	100 to 1,000 Å	Detectable only above 60 mi	---
UV (ultraviolet)	1,000 to 2,000 Å	Penetrates weakly to 50 to 60 mi	---
	2,000 to 3,000	Penetrates weakly to 15 to 20 mi	
	3,000 to 4,000	Penetrates to 15 to 20 mi; weakly to ground	Spectral lines (aurora, airglow)
Visible	4,000 to 7,000 Å	60 to 90% transmitted to ground	
IR (infrared)	0.7 to 5μ	Penetrates to 8 to 10 mi and generally to ground (major exceptions 2.5 to 2.7μ and 4.2 to 4.4μ).	Airglow and aurora; transparency fluctuations; scattering
	5 to 30μ	Penetrates to ground in 8 to 14μ and 16 to 24μ windows.	CO_2 and H_2O emission bands at several wavelengths; H_2O emission (sky noise)
	30 to 700μ	Penetrates to 8 to 10 mi.	
Millimeter waves	0.7 to 10 mm	Penetrates to 8 to 10 mi; Penetrates to ground except near 2.5 mm and in 4 to 6 mm range.	H_2O emission
Radio waves	1 cm to 30 m	Penetrates to ground	Man-made interference
LF radio	30 to 60 m (10 to 5 MHz)	Penetrates weakly to ground	Ionosphere disturbances during solar active periods, causing severe LF noise; man-made interference
	60 to 1,000m (5 to 0.3 MHz)	Penetrates to 500 to 1,000 mi; Penetrates weakly to 200 to 300 mi	

Table 3-17

DATA FOR AIRCRAFT, ROCKETS, BALLOONS, AND UNMANNED SATELLITES AS ASTRONOMICAL INSTRUMENT PLATFORMS

Vehicle Class	Specific Model	Mission Operational Altitude	Time On Station	Payload Weight	Remarks
High-Altitude aircraft	Convair 990 (NASA-Ames)	39,000 ft (7.4 mi)	To 5 hr	To 5 tons	Plus ≈ 40 crewmen, passengers
	Lear Jet	50,000 ft (9.5 mi)	To 2 hr	500 lb	Pilot plus 1 or 2 passengers
Balloons	Proved polyethylene	21 mi	1 to 30 days	2,200 lb	(1)
	Proved Mylar scrim	21 mi		5,500 lb	
Sounding rockets	Aerobee 150	50 to 110 mi	5 min	300 lb	(2)
	Aerobee 350	50 to 260 mi	9 min	300 lb	
Unmanned Earth satellites	Explorer	200 to 500 mi	10 mo to 10 yr*	200 lb	High orbits, interplanetary trajectories also possible
	Orbiting astronomical observatory (OAO)	400 to 500 mi	2 yr*	4,000 lb	

NOTES: *Limits set by instrument operating lifetimes.

(1) High Altitude Balloons as Scientific Platforms, by A. L. Morris and K. H. Stefan, NCAR, Boulder, Colorado, Jan 1969, p. 15.

(2) A Long-Range Program in Space Astronomy (position paper of the Astronomy Missions Board), NASA Publication SP-213, July 1969, p. 187.

currently being explored to improve high-resolution imagery beyond the atmospheric turbulence limits. Improvement in the gain and resolution of electronic image intensifiers offers the prospect of fainter threshold capabilities of ground-based telescopes and spectroscopy with finer wavelength resolution. Techniques such as these tend to reduce the need for some orbital observations, though not all, since the applications are limited. For example, interferometry is not two-dimensional imagery. Also, it cannot ensure improved spectroscopic or photometric observations of point sources as can the high resolution capability of large orbiting telescopes.* For this reason, the consideration of alternative instrumental techniques was applied only to critical issues relating to stellar diameters and double-star resolution.

A summary of earth-orbital versus non-orbital critical issue assignments by wavelength range and broad object categories is given in Table 3-18. In applying the general results of Table 3-18 to individual critical issues listed in Appendix B, Table 3, some mixed issues of the type that include earth orbital observations, were included with the pure earth orbital candidate issues. The results are summarized as follows:

A.	Manned earth orbital candidate (3-XX)	154
B.	Unmanned earth orbital candidate (UM)	21
C.	Non-earth-orbital candidate (NS)	240
D.	Principally concerned with Space Physics (SP)	26
E.	Redundant with another critical issue (PS)	155
F.	Deferred, requires advanced study (AC)	156
		752

Individual critical issue assignments are indicated in Table 3, Appendix B, by use of the code symbols shown in parentheses above.

3.4.2 Screening for Manned-Earth-Orbital-Research Applicability

Direct human participation in orbital astronomy offers a number of benefits as well as possible detriments to quality observations. The beneficial activities occur in five well-defined categories:

*Orbital Astronomy Support Facility Study, Vol. II, Part 2 (DAC-58142), July 1968, pp. 143-158.

Table 3-18

IDENTIFICATION OF CRITICAL ISSUES BY WAVELENGTH (OR ENERGY) RANGE AND BROAD OBJECT OR SOURCE CATEGORIES

KEY:

G	Ground-based	AG	Atmospheric emission good
B	Balloon	TA	Turbulence of atmosphere a problem
A	High-altitude aircraft	AS	Atmospheric scattering interferes
R	Sounding rockets	AE	Atmospheric emission interferes
EO	Earth orbit	LI	Large instrument(s) required
P	Space probe	SI	Small instrument(s) adequate
S	In situ	LOT	Long observation times required
AP	Atmospheric transmission a problem	SOT	Short observation times adequate

Wavelengths or Energies	Objects or Sources	Assignment of Critical Issues	Criteria
Gamma rays E > 10^4 Mev	All	G	AG
0.1 to 10^4 Mev	Background, large diffuse	EO	AE
	Small diffuse, discrete	B+EO	AE, LI
X-rays 0.2 to 20 kev	Discrete	EO	AP; LI; LOT; (1)
	Background, large diffuse	R+EO	SI; SOT
XUV 100 to 1,000 Å	Sun	R+EO	AP, SOT; (2)
UV 1,000 to 4,000 Å	Sun	R+EO	AP, SOT; (2)
	Bright planets and stars	R+EO	AP, SI; SOT
	Faint stars, nebulae galaxies, quasars	EO	AP, LOT
Visible 4,000 to 7,000 Å	Fine planetary detail	B+EO+P	TA, LI
	Discrete objects in galaxies,	EO	LI, LOT, TA
	Galaxies, quasars	EO	LI, LOT; TA
	Solar photosphere detail	G+B+EO	SOT
	Solar corona detail	G+EO	AS; LOT, (3)
IR 0.7 to 30μ 30 to 700μ	Background, large diffuse	R+EO	AP, AE; SI, SOT
	Discrete	A+B+EO+G	AP; AE; LI; LOT; (4)
Millimeter waves 0.7 to 10 mm	Discrete	G	AG, LI
	Diffuse, background	R+G	AG; AE
Radio waves 1 cm to 30m	All	G	AG; LI
LF radio 30 to 60m	All	G+R+EO	AP, LI
60 to 1,000m	All	EO	AP; LI; (5)

NOTES

(1) Refers to high angular and/or spectral resolution observations of strong discrete sources, or detection and coarse measures of weak sources.

(2) Actual assignments follow ongoing programs, e.g., OSO series.

(3) EO particularly for outer corona structure and temporal structure variations of whole corona, i.e., data not obtainable during eclipses.

(4) Refers to high precision radiometry of strong sources or detection and coarse radiometry of weak sources.

(5) Preferably at orbit altitude ≥ 1,000 km (600 mi).

A. Deployment, assembly, or erection of instruments in orbit.

B. Maintenance of orbital instruments in proper working order (repair, replacement of parts, replenishment of expendables).

C. Exchange of analyzer-sensor packages (e.g., spectrographs, cameras, photometers, image tubes) on major instruments.

D. Instrument performance evaluation, ranging from initial checkout to periodic re-examination of operating performance.

E. Observational participation, including cooperation with ground-based principal investigators, evaluation of observational data, and perhaps some cases of autonomous action.*

These functions indicate that man's greatest potential role in orbital astronomy is closely associated with the use of large, complex, and multipurpose instruments. Some examples are large-aperture optical telescopes, medium-aperture telescopes accommodating many types of secondary instrumentation, large-area x-ray detectors, very large LF radio antennas, and large, focusing x-ray telescopes. Other possibilities are large gamma ray detectors and medium-size LF antennas of complex geometry. Such instruments have well defined observational capabilities which can be related to research objectives or critical issues. Thus, the set of above activities can be used as a basis for screening the critical issues for their applicability to manned orbital astronomy. This can be done by deducing which issues would involve observations using major instruments of the sort mentioned. A total of 154 such manned candidate issues were thus identified. These issues are listed in Appendix C in conjunction with descriptions of the research clusters with which they are identified.

Possible detrimental effects of human presence or of manned facilities on quality orbital astronomical work are:

A. Spacecraft effluent production resulting in orbital environment contamination, a potential problem for optical observations of faint

*This category does not necessarily imply the need for a human observer <u>in orbit</u>, and thus has been given little weight in critical issue assignments.

diffuse sources.

B. Impulsive acceleration disturbances of telescopes outisde the response limits of their guidance stabilization systems (e.g., disturbances due to spacecraft crew motions), a possible detriment to high angular resolution optical observations.

C. LF radio interference generated by spacecraft electrical systems.

D. Psychological and physiological disturbances of performance, such as hallucinations and judgmental errors due to disorientation.

E. Conflicting experimental requirements of the other disciplines in a multipurpose space station, such as deliberate overboard dumps of liquid to study crystal formation in the near-vacuum of earth orbital space.

These effects constitute a second (negative) filter for manned orbital astronomy research. However, the following is noted concerning application of this filter to the screening of critical issues:

A. The spacecraft corona and crew motion mechanical disturbance problems can be circumvented by deploying susceptible instruments in remote free-flying modules or subsatellites. This procedure would also eliminate experimental conflicts with other disciplines.

B. To surmount geocorona attenuation, all LF radio antennas will be located in orbits well above 1,000 km where long-duration manned stations are not likely to be established, at least in the time period considered. This very nearly eliminates the manmade interference problem.

C. Physiological and psychological performance disturbances remain the least understood of the negative effects; their detailed discussion is proper to the Manned Space Flight Capability discipline of this study. If such negative effects prove serious (based on evaluation under realistic conditions of extended orbital missions) and they cannot be overcome, then direct human participation in orbital astronomy would be virtually ruled out. On the other hand, if performance disturbances or handicaps prove minor and manageable, then all the beneficial activities listed earlier will be feasible in orbit.

An optimistic view permits the conclusion that detrimental effects do not automatically preclude any candidate orbital astronomy research. It follows that the manned candidate critical issues become the manned issues.

3.4.3 Ongoing Programs

The ongoing programs in space astronomy examined in the present study include those utilizing as instrument platforms aircraft, balloons, sounding rockets, and earth orbital vehicles.

The ongoing programs have been divided as follows:

A. Earth-orbital missions of firm status and with well-defined objectives;

B. Suborbital (such as aircraft) missions, with probable observing programs extrapolated from past and current activities;

C. Interplanetary/planetary probe or in situ missions, with partial experimental data, including projections from past missions.

Observing programs for the above missions and instrument complement data for the earth orbital missions are summarized in Tables 3-19, 3-20, and 3-21, respectively. Table 3-22 lists detailed data for the solar ATM-A experiments on the Skylab A mission-the only substantial "manned" orbital astronomy program definitely planned. None of the critical issues selected for the manned program were judged to be fully satisfied by any combination of ongoing programs. No critical issues were dropped as a result of this screening.

3.4.4 Grouping of the Manned Earth-Orbital Critical Issues into Research Clusters

The 154 critical issues associated with manned earth-orbital research were grouped into seven research clusters based principally on common measurements and common major observing instruments. Table 3-23 summarizes the defining characteristics of the research clusters and the instruments.

3.4.5 Brief Description of the Research Clusters

In summary, in the discipline of Space Astronomy, seven research clusters were

Table 3-19

ONGOING EARTH-ORBITAL ASTRONOMY OF THE 1970'S

Programs Key (also applies to Table 3-23)

A	- Aircraft (35,000 to 50,000 ft operating altitude)
B	- Balloons (stratospheric)
R	- Sounding Rockets
OAO	- Orbiting Astronomical Observatory
OSO	- Orbiting Solar Observatory
SAS	- Small Astronomy Satellite
SES	- Solar Explorer Satellite
RAE	- Radio Astronomy Explorer
ATM	- Apollo Telescope Mount

Letters following the above (e g., SAS-A) designate the order in a planned sequence of missions. Numbers (e g., OAO-2) indicate a mission in operation or completed.

Vehicle Designation	Observing Programs	Principal Instruments
SAS	Weak discrete x-ray source sky survey and monitoring of known strong sources for variability (SAS-A); Sky survey for diffuse high-energy gamma-rays with coarse angular resolution (SAS-B)	X-ray telescopes (SAS-A)
RAE-B[1]	Locate some strong discrete LF radio sources (using moon as occulter) and obtain flux-frequency distributions	Short dipoles, V and/or X antenna
OAO	UV 4-band sky survey (mostly for spectral type O-G stars), broadband photometry and coarse spectrometry of bright spectral type O-A stars, some emission nebulae, some planets and some galaxies (OAO-2); UV moderate-resolution stellar (all types) and emission nebulae spectrometry and spectrophotometry (OAO-B), high-resolution UV stellar spectrometry, probably also including nebula and planet observations (OAO-C)	Four 12-inch telescopes with TV cameras, 4 photoelectric photometers, and 2 scanning spectrometers (OAO-2), 38-inch telescope with scanning spectro-photometer (OAO-B), 32-inch diffraction-limited telescope with scanning spectrometer (OAO-C)
SES	Broadband x-ray photometric patrol of sun as part of flare warning system	X-ray photometers, Geiger tubes
OSO[2]	UV spectroscopy of small solar disc areas, x-ray spectroscopy (solar corona flares) with good angular resolution (OSO-6), x-ray and XUV monochromatic imagery with good angular resolution (OSO-H); K-coronagraphy (OSO-I), XUV and UV spectroscopy of small disc features with high resolution and photometric precision (OSO-J)	UV and x-ray spectrographs (OSO-6), x-ray spectroheliograph, XUV spectro-heliometer (OSO-H); K coronagraph (OSO-I), XUV-UV spectrograph (OSO-J)

[1] To be located in lunar orbit. Antennas assumed similar to those of RAE-1.

[2] Description of OSO-I and later missions is not consistent in the references consulted.

Table 3-20

ONGOING SUBORBITAL SPACE ASTRONOMY PROGRAMS OF THE 1970's

Platforms	Observing Programs or Experiments
Aircraft[1]	Solar eclipse chromosphere spectroscopy (visible and IR), coronal imagery, photometry, polarimetry, spectroscopy (mostly visible wavelengths); solar far-IR radiometry, planetary IR spectroscopy; IR-submillimeter radiometry of discrete 'peculiar' sources; IR stellar radiometry and spectroscopy; photographic searches for the Earth-Moon liberation point 'clouds'; Zodiacal light photometry; comet imagery.
Balloons	High-resolution solar photosphere and planetary photography (visible wavelengths); stellar and nebular high-resolution imagery; solar gamma ray searches; search for low-energy gamma radiation from known discrete x-ray sources; improved measures of diffuse gamma ray flux levels and angular distribution; searches for any discrete gamma ray sources; visible wavelength imagery and/or photometry of Earth-moon libration point clouds, Zodiacal light; IR solar, planetary, and stellar spectroscopy; peculiar IR source radiometry.
Sounding Rockets	Solar x-ray and XUV spectroheliography (monochromatic imagery); solar x-ray, XUV, and UV spectroscopy and spectrophotometry; solar corona white-light imagery, planetary UV photometry (broad- and narrow-band) and coarse spectroscopy; moderate-resolution UV spectroscopy of bright early-type stars; photometric monitoring of strong discrete x-ray sources for variability; searches for newly appearing strong discrete x-ray sources; x-ray diffuse background photometry for better determination of flux levels and angular distribution; IR sky surveys for diffuse background flux levels and angular distribution, monitoring of some strong discrete sources; LF radio radiometry of the diffuse LF background.

[1] Examples: NASA-Ames Convair 990 and Lear Jet.

Table 3-21

ONGOING PLANETARY FLYBY, ORBITER, INTERPLANETARY PROBE, AND *IN SITU* EXPLORATION PROGRAMS OF THE 1970'S

Mission and Dates	Scientific Measurements, Observations, Experiments
Apollo 14, 16, 17 (1971-72)	Lunar surface exploration, soil sampling (physical, chemical, mineralogical composition; soil strength, thermal properties, density, age), subsurface and internal structure determinations (coring, seismometry); improved lunar orbit element determinations
Mars Mariner (1971, two flights)	Mars surface mapping (TV imagery) to 0.1 km resolution in selected areas, 1-10 km over most of disc; IR surface radiometry (temperature distribution, surface material thermal property determinations; UV photometry (atmospheric scattering property determinations); active atmospheric density probing (radio occultation experiment)
Viking: Mars Orbiter and Soft Lander (1975)	Mars soil composition determination; search for organic/biological materials; surface imagery with very-high-angular resolution; high resolution monitoring of meteorological phenomena
Venus Mariner[1], (1973 and/or 1975)	Direct measures of atmospheric pressure from high altitudes to surface; temperature and magnetic field measures[2]
Venus-Mercury Flyby (1973-74)	Venus observations probably similar to Venus Mariner, above; Mercury surface TV imagery with high angular resolution
Pioneer F, G: Jupiter Flybys (1972, 1973)	High resolution TV imagery of Jupiter's cloud layer features, possibly also of one or more satellites; direct magnetic field measures; IR radiometry of the disc with good angular resolution; asteroid imagery; micrometeoroid sampling in Asteroid Belt
Sunblazer[2] Small Interplanetary Probe	"Active" determination of solar corona electron density variation with height by means of radio occultation; direct magnetic field measurements; solar cosmic ray flux measures

[1] Includes an atmospheric drop sonde; main vehicle will be flyby.

[2] Approximate dates 1970-1973. A few other small interplanetary probes will be launched, generally with the same sort of measurement goals as Sunblazer.

Table 3-22

DESCRIPTION OF SOLAR ATM-A EXPERIMENT SET ON SKYLAB A
(1972 LAUNCH)

- Objectives: To determine XUV emission line profiles from active centers and to obtain monochromatic XUV images of active centers in time sequences, which data will increase knowledge of the temporal development of active regions and the energies involved. To better determine the structure of the chromospheric network. To obtain relatively high spectral and angular resolution x-ray images of active centers in time sequences. To record and monitor the two-dimensional structure of the white-light middle and outer corona over time intervals greatly exceeding eclipse times.

- Instruments: Scanning spectrometer and spectroheliometer for UV and XUV regions. XUV slitless spectroheliograph. High-resolution photographic spectrograph (UV). Large-field x-ray telescope with filters and photographic recording. Small-field x-ray telescope with slitless spectroheliograph. White light photographic coronagraph.

- Performance: UV-XUV spectrometer-spectroheliometer: 300 to 1300 Å. Slitless XUV spectroheliograph covers 300 to 650 Å. UV spectrograph will cover the entire UV band (900 to 4,000 Å), with high spectral resolution (presumably < 1Å). The two x-ray instruments will work in the 2 to 60 Å band, the coronagraph in visible wavelengths (broadband). The coronagraph is sensitive to coronal radiation from 1.5 to 20 solar radii.

- References:

(1) Experiment Program for Extended Earth Orbital Missions (NASA), Vol. I, Sept. 1, 1969.

(2) A Long-Range Program in Space Astronomy (Position Paper of the Astronomy Mission Board), NASA Publication SP-213, July 1969, p. 171, Table 4.

TABLE 3-23

RESEARCH CLUSTERS OF CRITICAL ISSUES
FOR MANNED ORBITAL ASTRONOMY

Cluster Designation	Interpretation	Astronomical Objects or Sources	Adopted Major Instrument
3-OS	Optical surveys (Small fields of view)	Unknown objects (general), intergalactic globular clusters, HII regions and luminous stars in moderately distant galaxies, main sequence stars in globular clusters (of the galaxy), optical counterparts of x-ray and peculiar IR discrete sources, and pulsars, unknown solar system bodies, unknown planetary satellites, micro-asteroids	1-meter diffraction-limited telescope followed by 3-m telescope with 0.1 arc-sec resolution at 4000-5000 Å
3-OW	Optical structure and spectra of faint or small objects	Galaxies, quasars, nuclei and other small areas of nearby galaxies, galactic dense nebulae and globules, Uranus, Neptune, Pluto, large planetary satellites, comet nuclei	3-meter diffraction-limited telescope
3-OB	Optical study of bright planets	Mars, Mercury (near UV, visible, near IR wavelengths)	1- and 3-m diffraction-limited telescopes
3-OP	Optical stellar high-precision photometry	Nearby dwarf stars, cepheids and other variables, selected non-variable stars	Any of the above (No Research Cluster Description written)
3-SO	Solar optical studies	Solar photosphere and chromosphere, especially small features (spots, flares, spicules, prominences)	1.5-m telescope with 0.1 arc-sec resolution at 5000 Å (No Research Cluster Description written)
3-XR	Location and structure of x-ray sources	Known and unknown x-ray sources (chiefly discrete sources)	Large area proportional counter array; large-aperture focusing telescope
3-LF	Location, structure, and spectra of low frequency radio sources	Radio galaxies and quasars, nucleus of the Galaxy, large structures of the galactic disc plasma and galactic corona, galactic HII regions	10-km rhombic plus short dipole array interferometric antenna

formed from the 154 critical issues judged to be suitable for a manned Earth-orbital research program. A brief description of these research clusters is presented below. More detailed descriptions are given in Appendix C.

DISCIPLINE SYNOPSIS

Space Astronomy

1. Research Objectives

Three general research objectives of the manned orbital astronomy program are defined in this study:

A. To discover new objects of known types and possibly to discover presently unknown classes of objects or phenomena;

B. To extend precision measurements to new wavelength ranges;

C. To perform observations in presently accessible wavelengths with improved precision.

2. Background and Current Status

All observations related to the research clusters can be performed to one degree or another using either ground-based instruments or platforms other than manned orbital research facilities; however, measurement limitations—sometimes critical—result in all such cases. For example, photography of faint stars or galaxies from ground observatories rarely achieves angular resolution better than 1-2 arc-seconds due to atmospheric turbulence; rocket x-ray observations of discrete sources are limited to objects producing flux densities greater than 10^{-11} erg cm^{-2} sec^{-1} keV^{-1} near 10 keV due to short observation periods; automatically deployable LF radio antennae, necessarily of moderate size compared to the measurement wavelengths, can only achieve angular resolutions of tens of degrees or a few degrees using the moon's disc as an occulting source. A number of other similar limitations could be listed.

The only "manned" orbital astronomy mission definitely scheduled is comprised of the Skylab solar ATM-A experiments. Because this mission was originally conceived for an unmanned spacecraft, it does not utilize man in certain roles where he could be most useful to orbital astronomy. Men have also been active as observers in connection with the OAO-2 mission-but via remote, ground-based control of the satellite; thus the mission does not really qualify as man-supported (in the sense that the present study does), but does illustrate that the need for man as an observer in orbital astronomy need not mean man in orbit.

3. Description of Research

Table 3-24 summarizes the observing programs covered by the combined group of seven research clusters by object, source, or phenomenon type, and by type of measurement.

4. Impact on Spacecraft

Table 3-25 summarizes man's role in the programs under discussion. From Table 3-25 it may be seen that no clear requirement is indicated for man in orbit as an observer. Furthermore, the deployment, assembly, and maintenance functions-in which there is a definite requirement for man-involve only one-time or occasional activities. Therefore, it can be concluded that continuously manned stations are not essential to the support of orbital astronomy facilities.

The optimum orbit altitude was selected on the basis of these three factors:

A. Accessible sky area, which determines whether long photographic exposures or electronic integrations will be possible without interruption by earth occultation. Occultation leads to the requirement for re-acquisition of target objects which is costly in terms of observing time and probably degrading of angular resolution.

B. Orbital-velocity-induced differential aberration of light from astronomical sources. Differential aberration restricts the field of view over which a given angular resolution can be achieved and complicates off-axis guidance.

C. Orbital-velocity-induced Doppler shift of spectral lines in astronomical sources. Doppler shift causes smearing of the natural line profiles and degradation of wavelength resolution.

These factors (analyzed for circular orbits in the OASF Study, Vol. II, Part 2, pp. 158-170) had to be applied only to the three stellar optical telescopes;

TABLE 3 - 24

BROAD OBSERVATION PROGRAMS OF THE RESEARCH CLUSTERS

Astronomical Object, Source, or Phenomenon \ Type of Observation	Search, Survey, Astrometry	Imagery	Photometry or Radiometry	Spectroscopy
Gamma ray sources	Treated in Space Physics discipline of the study			
Gamma ray background				
X-ray sources	1	1,3	1,3	3
X-ray background	1	1	1	
Peculiar IR sources	4,2,6	2,4,6	2,4,6	
MM-wave background				
LF radio sources	5	5	5	
LF background	5	5	5	
Neutron stars, pulsars, supernovae remnants	1,2,4,6	1,2,3,4,6	1,2,4,3,6	3
Active galaxies	1,2,5,4,6	1,2,4,3,6,5	1,2,4,3,6,5	3
Quasars	5	2,5,4,6	2,4,5,6	2,4,6
Globules, protostars, planetary nebulae		2,4,6	2,4,6	(2)
Stars		2,4,6	2,4,6	2,4,6
Diffuse emission nebulae		(2)	2,4,6	
H II regions	5	5	(2)	(2)
Star clusters	2,4,6	2,4,6	2,4,6	
Interstellar gas	1,5	1	1	2,4,6
Interstellar dust			2,4,6	
Galaxies	5	2,5,6,4	2,5,4,6	2,4,6
Intergalactic gas	1,5	1	1,5	
Cosmic thermal radiation				
Planets	2,(5),4,6	2,4,6	(5)	(2)
Satellites and asteroids	2,4,6	2,4,6		
Comets, interplanetary gas	5		(5)	(2)
Interplanetary dust				
Solar photosphere and chromosphere, solar corona	(5),(7)	(3),(7)	(5),(7)	(7)
Cosmic rays	Treated in Space Physics discipline of the study			
Gravitational radiators				

Legend
1 - X-ray detector array (3-XR)
2 - 1-m diffraction limited optical telescope (3-OB, 3-OS, 3-OP)
3 - Focusing x-ray telescope (3-XR)
4 - 3-m non-diffraction-limited optical telescope (3-OS, 3-OP)
5 - KM wave telescope (3-LF)
6 - 3-m diffraction limited optical telescope (3-OW, 3-OB, 3-OP)
7 - 1.5-m diffraction limited solar telescope (3-SO)
( ) = Observations not included in the research clusters

Table 3-25

ASTRONOMICAL INSTRUMENT SUPPORT BY MAN

Major Instrument \ Instrument Operation Phase	Assembly	Deployment (Unit)	Operational Preparation	Target Acquisition	Observation	Maintenance
X-ray Detector Array	P	D	P			P
1-Meter Diffraction-Limited Optical* Telescope		D	D	D†	P†	D
Focusing X-ray Telescope	P	D	D	D†	P†	D
3-Meter Non-Diffraction-Limited Optical* Telescope	P	D	D	D†	P†	D
KM Wave Orbiting Telescope		P	P			D
3-Meter Diffraction-Limited Optical* Telescope	P	D	D	D†	P†	D

D = Definite support requirement for man
P = Possible support requirement for man
*UV, Visible, and near IR wavelengths
† Man not necessarily in orbit

orbits for the other major instruments are largely dictated by other factors. Numerical results for low (200-500 nmi) and synchronous (19,300 nmi) altitudes are given in Table 3-26, from which the following observations may be drawn:

A. Nearly all astronomical sources will be periodically occulted by earth from low orbits, necessitating re-acquisition whenever exposures exceeding ≳ 1 hour are required. At synchronous orbit altitudes, however, much of the celestial sphere will be permanently accessible and earth will occult the remaining portions only at 12-hour intervals. These results indicate that the 3-m diffraction-limited telescope, for best performance and efficiency, should be located in a high orbit. The 1-m diffraction-limited and the 3-m nondiffraction-limited telescope, with lesser resolution capability and less long-exposure programming, can operate satisfactorily in low orbits.

B. Field of view restriction due to differential light aberration is not serious at visible wavelengths in low orbits; however, it would be

TABLE 3-26

ORBITAL ALTITUDE EFFECTS ON OPTICAL OBSERVATIONS

Orbital Altitude (nmi)	Orbit Period	Unobstructed Sky Area† Periodic (percent)	Unobstructed Sky Area† Permanent (percent)	Field Diam for 0.04 Sec Resolution* (arc-min)	Maximum Doppler Line Broadening at λ 2000 Å* (angstroms)
200	100 min	61.6	2.7	12.7	0.11
500	110 min	72.0	10.1	13.2	0.10
19,300	23.9 hrs	99.4	84.7	31.8	0.041

†Earth radius increased by 100 nmi to account for the atmosphere.
*For photographic exposures or electronic sensor integrations of one-half orbital period, with line of sight in orbital plane. For lines of sight at inclination i to the orbit plane, multiply the Doppler broadening by cos i. There is no significant effect of i on the light aberration-restricted field of view.

if the optics were figured for diffraction-limited performance in UV wavelengths, as discussed by W.G. Tifft (Astronautics and Aeronautics, Vol. 4, 1966, pp. 40-53). Guiding on a bright star 15 to 30 arc-min from the center of the field will, however, be complicated by the differential aberration. If offset guidance requires relatively bright guide stars—which are rare—these results somewhat favor a high earth orbit for the 3-m diffraction-limited telescope. The differential aberration is unimportant in the case of the other two optical telescopes.

Doppler spectral line broadening due to telescope-spectrograph orbital motion will be substantial in the UV wavelength range for low-orbit observing locations. This will most seriously affect the angular resolution and light-gathering power, consequently inhibiting very high spectral resolution using small slit widths. Although not emphasized in Research Cluster Description 3-OW, a large number of UV slit spectroscopy observations will be required as follow up to early programs;hence a high-orbit location is indicated in order to achieve wavelength resolution consistently better than 0.1Å. Low orbits appear acceptable for the other telescopes on this basis.

5. Required Supporting Technology Development

Common to all the optical research clusters is the requirement to develop high-resolution large-aperture optical systems, along with high precision guidance stabilization systems. The area of precision target acquisition needs more study; available studies are generally pessimistic concerning totally automatic pointing. Thermal degradation of optics must be overcome. Finally, a reliable method for alignment of the optical systems in orbit following deployment must be developed.

In the area of imaging sensors, there remains the question of film versus electronic media. This problem has an impact on two other problem areas: (1) data management (electronic imagery) and (2) logistics (film handling, protection, and supply).

In the area of x-ray detectors, elimination of spurious background radiation is the chief area of technological development. LF astronomy appears mainly concerned with antenna materials development and deployment modes, including further study of how man could be used in such programs.

Since the most important human roles in support of orbital astronomy are in-orbit deployment, assembly, and maintenance of instruments, EVA skill development is essential.

3.5 SCREENING AND GROUPING OF CRITICAL ISSUES IN SPACE PHYSICS

The critical issues in Space Physics were screened and grouped with respect to the following criteria: (1) space research applicability, (2) manned space research applicability, (3) contributions from ongoing programs, and (4) commonality of experiments.

3.5.1 Physics and Chemistry Laboratory

The concept of a physics and chemistry laboratory onboard a manned space station was introduced earlier (Subsection 2.5.1.3). Critical issues relating to this laboratory were developed at various positions in the overview. The screening of these critical issues was aided by the matrix display and screening criteria shown in Table 3-27.

3.5.1.1 Screening for Space Research Applicability

The screening criteria applied with regard to space research applicability (Table 3-27) were divided into two major categories: (1) orbital characteristics, and (2) space environment characteristics. Since the orbital characteristics had almost no bearing on the critical issues for the physics and chemistry laboratory, the space environment characteristics essentially became the criteria for selection. These characteristics were:

1. Long-term low gravity
2. High pumping speeds
3. Meteoroids
4. Plasma conditions
5. Cosmic radiation
6. Radiation belts
7. Above the atmosphere
8. Solar radiation
9. Large vacuum volume (no wall effects)

FOLDOUT FRAME 1

Table 3-27 3-22

SCREENING OF CRITICAL ISSUES FOR PHYSICS AND CHEMISTRY LABORATORY

SCREENING OF CRITICAL ISSUES FOR PHYSICS AND CHEMISTRY LABORATORY

Definition of Symbols

E = Essential
H = Helpful
N = No Effect
T = Tolerable
I = Intolerable
U = Effects Unknown

Column groups: Space Research Selection Criteria (Orbital Characteristics; Space Environment Characteristics) — Manned Space Research Selection Criteria (Participation of Man: Scientist Observer, Development & Operations Engineer, Technician; Flight Safety; Mission Performance Degradation) — Critical Issue Suitable for Manned Space Research (✓) — Relationship to Other Programs** — Requirements Not Satisfied by Other Programs (✓) — Applicable to Candidate for Future Manned Space Research (✓)

No.	Critical Issue
4.1.1.1.1.1.1	Is the total energy conserved in the universe?
[illegible]	Is entropy of universe steadily increasing?
[illegible]	Can it locally decrease?
[illegible]	How is chemistry of flames, combustion influenced by Zero-G?
[illegible]	How are characteristics of explosive phenomena influenced by Zero-G?
[illegible]	What are the thermodynamic properties and density profiles of liquids in the critical region under zero G conditions?
[illegible]	How do liquid-vapor interfaces behave in low-G?
[illegible]	What are characteristics of steady state boiling curve in Zero G?
[illegible]	What parameters characterize heat transfer in nucleate boiling?
[illegible]	How do metals sublime and condense in Zero G?
[illegible]	How do gas clouds expand in space environment?
[illegible]	What is density, chemistry, and energy distribution in expanding gas clouds?
[illegible]	How do superfluids behave in weightless state?
[illegible]	How do gases diffuse through porous media?
[illegible]	What is viscous behavior of superfluids in space?
[illegible]	How is thermal conductivity, diffusivity of gases, liquids affected in Zero-G?
[illegible]	How are free and forced convection influenced by Zero G?
[illegible]	How is boiling heat transfer influenced by Zero G?
[illegible]	What is behavior of chemical reactions in Zero G?
[illegible]	How do chemical reactions occur in absence of walls?
[illegible]	How are energy states, charged particles distributed in expanding gases?
[illegible]	What is energy, density distribution among particles in expanding gas cloud?
[illegible]	What is energy, density distribution in high pressure waves?
[illegible]	What kind of random, particle fluctuation exists in ensembles of particles?
[illegible]	How are phase changes affected by electric, magnetic fields in Zero G?
[illegible]	How is heat transfer, energy dissipation in rotating liquid affected in Zero G?
[illegible]	Surface to surface radiant exchange?
[illegible]	Absorbing and self emitting media interactions
[illegible]	What are mechanical properties of uniform mixed composite materials in Zero-G?
[illegible]	Do compacted powders, composites made in space behave same as those made on earth?
[illegible]	What is equilibrium configuration of rotating liquid as function of gravity?
[illegible]	What are exact shapes and surface properties of free-cast materials?
[illegible]	What are oscillatory, relaxation times of liquids in Zero-G?
[illegible]	What are oscillation periods, shapes of free liquid drops in Zero-G?
[illegible]	What configurations do liquids assume in Zero-G in specific containers?
[illegible]	How do electric and magnetic fields affect dielectric, conducting liquids in Zero-G?
[illegible]	How are free shapes, properties of melts affected by cohesion, surface tension?
[illegible]	What are geometrical tolerances of free-cast bodies?
[illegible]	What is microsurface structure of free-cast bodies?
[illegible]	How does capillary flow in Zero G depend on properties of liquids, surfaces?
[illegible]	What is dynamical behavior of solid particles in Zero G?
[illegible]	What are characteristics of vortices in Zero G?
[illegible]	What is viscous behavior, self-diffusivity in high pressure gases in Zero-G?
[illegible]	How can structures of uniform density of suspended particles be done in Zero-G?
[illegible]	Can Space be used to make castings with specific density distributions?
[illegible]	How is adhesion, layer coating influenced by Zero G?
[illegible]	How can spin be used for controlled density casting?
[illegible]	How do small particles behave in liquid under Brownian motion in Zero G?
[illegible]	How does liquid mixing in zero-g differ from that in one G?
[illegible]	How do free liquid droplets interact?
[illegible]	How do bubbles move in Zero G, what are acting forces?
[illegible]	How do bubbles grow in Zero G, what are oscillation characteristics?
[illegible]	Is it feasible to produce glassy foam of uniform density in space?
[illegible]	What are effects of Zero G on liquid adhesion, also distribution of liquid drops?
[illegible]	What are surface wave propagation characteristics of liquids in Zero G?
[illegible]	What is significance of Rayleigh instabilities of Zero G?
[illegible]	Can space be used to improve quality of glassy materials?
[illegible]	Can space be used to cast better lenses and blanks?
[illegible]	Can whisker growth be improved in Zero-G?
[illegible]	What are effects of gravitational potentials on quantum states at low temperatures?
[illegible]	How are electrical and optical properties of semiconducting surfaces affected by ultra clean environment?
[illegible]	How are electronic surface emission phenomena affected by cleanliness of space?
[illegible]	What are secondary electron emission phenomena from very clean surfaces?
[illegible]	How are properties of semiconductors affected by space radiation?
[illegible]	What are effects of gravity on solidification and crystal growth?
[illegible]	How can these effects be used to improve industrial quality crystals?
[illegible]	Is it possible to grow single, giant crystals of high perfection?
[illegible]	How does weight stress elimination influence quality of crystals?
[illegible]	What are observable dependent parameters affected by Zero G?
[illegible]	What are advantages of zone refining of single crystal in Zero-G?
[illegible]	How can levitation melting be improved?
[illegible]	How can process of heat treatment be improved?
[illegible]	Is it feasible to make metal foam of uniform density in space?
[illegible]	How can vacuum melting and casting be improved in space?
[illegible]	How can vacuum, natural levitation in space be used to obtain high-purity materials?
[illegible]	What are properties of extremely high purity materials?
[illegible]	How are phenomena of surface chemistry affected by atmosphere-less surfaces?
[illegible]	What are catalytic effects of very clean surfaces?
[illegible]	What are friction coefficients of surfaces when clean surfaces?
[illegible]	What are contact properties of atmosphere-less materials?
[illegible]	What is "sticking probability" of gas molecules on clean surfaces
[illegible]	What are effects on properties of ultra clean surfaces?
[illegible]	What is adsorption energy between a solid surface and adsorbed gas?
[illegible]	[illegible]
[illegible]	Is space useful in generating thin films by sputtering, evaporation techniques?
[illegible]	Is space useful for surface deposition and surface tensile dimming of thin films?
[illegible]	Is fatigue behavior of materials in space similar to that in One g?
[illegible]	What are the optical properties of gaseous releases?
[illegible]	What are the optical properties of liquid particle dispersions?
[illegible]	What are the optical properties of small solid particles?

R-1. Absence of gravity is not required, also it is difficult to conceive a single experiment that would yield conclusive results.

R-2. All phenomena involved are either on a molecular scale or of such a small scale that the gravitational forces are insignificant in comparison with the forces responsible for the phenomena.

R-3. Earth gravitational effects can be overcome by proper experiment procedures.

R-4. Surface properties can be more accurately determined in an Earth bound laboratory. Also, the influence of a low g environment on the free-cast process itself is investigated in research clusters C/P-6. What is the effect of zero gravity on the production of materials having superior physical characteristics.

R-5. Concerned with electromagnetic radiation, which is not affected by a gravitational environment.

R-6. Involved phenomena are molecular or atomic effects. Also, much cleaner and harder vacuums are obtainable in an Earth laboratory than are found in space.

** ONGOING PROGRAM IDENTIFICATION

1. "Processes for Space Manufacturing", MSFC DCN 1-30 [illegible]
2. "Material Dumping, Positioning, Transporting, Spinning, and Agitating Devices for Manufacturing in Space", MSFC DCN 1-9-54 20095
3. "Space Environmental Effects on Solidification", MSFC DCN 1-7-PO [illegible]
4. "Project Thermo", NAS 8-[illegible]
5. "Extended Apollo Systems Utilization Study", NAS 9-[illegible]
6. Douglas MORL Program
7. Design and Delivery of a Unidirectional Solidification Furnace, MSFC

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FOLDOUT FRAME 2

Of these, the characteristics of long-term gravity, high pumping speeds, and large vacuum volume were of greatest importance.

Each critical issue was rated E (essential), H (helpful), or N (no effect). Critical issues failing to register at least one E were rejected as not being applicable for space research. Of the 90 physics and chemistry laboratory critical issues displayed in Table 3-27, 54 were retained on the basis of space research being essential in some respect. The other 36 objectives were eliminated, generally because the physical phenomena involved were judged to be insensitive to the gravity level. The specific reasons for rejection are annotated in Table 3-27.

3.5.1.2 Screening for Manned Space Research Applicability

The 54 critical issues retained in the screening for space research were screened for manned space research applicability. This screening, as may be seen in Table 3-27, consisted of three major criteria, each with several subtopics, as follows:

1. Participation of man.
   - A. Scientist/observer.
     - (1) Real-time data analysis and evaluation.
     - (2) Multiple sensor use.
     - (3) Sensor mode or parameter selection.
     - (4) Cooperation with principal investigator on ground.
   - B. Development and operations engineer.
     - (1) Spacecraft position or orientation control.
     - (2) Sensor operation and parameter variation.
     - (3) Evaluation of sensor design and performance.
     - (4) Component qualification testing.
   - C. Technician.
     - (1) Equipment setup, checkout, maintenance, and calibration.
     - (2) Servicing of sensor and equipment consumables.
2. Flight safety.
   - A. External environment extremes (such as radiation, temperature and vacuum).

B. Excessive physiological stress (such as weightlessness, fatigue, and dehydration).

C. Excessive psychological stress (such as sensory deprivation).

D. Crew safety effects (such as high voltage, noise level, and inflammables).

3. Mission performance degradation.

A. Acceleration disturbances (such as attitude control and crew mobility).

B. Effluent release (such as environmental contamination).

C. Repetitive duty cycles (such as continuous high-precision observations).

Each critical issue was rated either E (essential), H (helpful), or N (no effect) in connection with participation of man and either N (no effect), T (tolerable), or I (intolerable) in connection with flight safety and mission performance degradation. Seven critical issues were rejected on the basis of a rating of I. Five other critical issues that were not rated E for any criterion were retained when it was later seen (Subsection 3.5.1.4) that they clustered with other critical issues that were rated essential.

3.5.1.3 Contributions of Ongoing Programs

The critical issues that were retained through both of the above screenings were then compared with ongoing programs. The portion of Table 3-4 (Subsection 3.1.3) that relates to Skylab A outlines the contributions to the physics and chemistry laboratory from the only ongoing program found to be directly concerned with this area. None of the experiments answered any of the research objectives completely, although they will be of benefit in providing experimental design criteria and data. As a result, none of the critical issues were eliminated in this analysis.

Other programs were examined for pertinence to the present study. Where useful data were obtained, the information was used in the analysis and description of experimental approaches. These programs are noted in Table 3-27.

3.5.1.4 Clustering of Critical Issues into Experiment Groups

The 47 critical issues that were retained after the screening described above were grouped into 11 research clusters, as follows:

Cluster No.	Title
4-P/C-1	Effect of the Space Environment on Chemical Reactions
4-P/C-2	Shape and Stability of Liquid-Vapor Interfaces
4-P/C-3	Boiling and Convective Heat Transfer in Zero-Gravity
4-P/C-4	Effect of Zero Gravity on the Production of Controlled-Density Materials
4-P/C-5	Effect of Electric and Magnetic Fields on Materials
4-P/C-6	Use of Zero Gravity to Produce Materials Having Superior Physical Characteristics
4-P/C-7	Improvements of Materials by Levitation Melting
4-P/C-8	Effect of Zero Gravity on the Production of Films and Foils
4-P/C-9	Effects of Zero Gravity on Liquid Releases and Liquid Drop Size Distributions
4-P/C-10	Capillary Flow in Zero Gravity
4-P/C-11	Behavior of Superfluids in the Weightless State

The principal objectives addressed in formulating these clusters and deciding which critical issues could be included were: (1) use of a single environmental chamber, with minor ancillary instrumentation and devices, to provide the information necessary to answer several critical issues; (2) obtaining required data through minor modification of the critical issues themselves, provided their basic objectives were not thereby compromised; and (3) obtaining information for several critical issues over the experiment time span by proceeding with the experimentation in a logical work sequence.

There is extensive equipment and facility commonality among the 11 research clusters. Table 3-28 demonstrates this commonality.

3.5.1.5 Brief Descriptions of the Research Clusters

In summary, in the physics and chemistry laboratory, 11 research clusters were formed from the 46 critical issues judged to be suitable for a manned earth-orbital research program. An overview of these research clusters is presented

EQUIPMENT OR FACILITY	ENVIRONMENTAL CHAMBER	FLUID PHYSICS CHAMBER	THERMAL CONTROL	PRESSURE REGULATOR	GAS SYSTEM	HEATING EQUIPMENT	ACCELEROMETER	TEMPERATURE SENSORS	CAMERAS
4-P/C-1 EFFECTS OF THE SPACE ENVIRONMENT ON CHEMICAL REACTIONS	X			X	X		X	X	X
4-P/C-2 SHAPE AND STABILITY OF LIQUID-VAPOR INTERFACES		X		X	X		X	X	X
4-P/C-3 BOILING AND CONVECTIVE HEAT TRANSFER IN ZERO G		X	X	X		X	X	X	X
4-P/C-4 EFFECT OF ZERO GRAVITY ON THE PRODUCTION OF CONTROLLED-DENSITY MATERIALS	X		X	X	X	X	X	X	
4-P/C-5 EFFECT OF ELECTRIC AND MAGNETIC FIELDS ON MATERIALS	X		X	X		X	X	X	X
4-P/C-6 USE OF ZERO GRAVITY TO PRODUCE MATERIALS HAVING SUPERIOR PHYSICAL CHARACTERISTICS	X		X	X	X	X	X	X	X
4-P/C-7 IMPROVEMENTS OF MATERIALS BY LEVITATION MELTING	X		X	X		X	X	X	X
4-P/C-8 EFFECT OF ZERO GRAVITY ON THE PRODUCTION OF FILMS AND FOILS	X		X	X	X	X	X	X	X
4-P/C-9 EFFECTS OF ZERO GRAVITY ON LIQUID RELEASES, SIZE DISTRIBUTION OF LIQUID DROPS		X		X	X		X	X	X
4-P/C-10 CAPILLARY FLOW IN ZERO GRAVITY		X	X	X	X		X	X	X
4-P/C-11 BEHAVIOR OF SUPERFLUIDS IN THE WEIGHTLESS STATE		X	X	X	X	X	X	X	X

Table 3-28. Equipment Commonality — Physics and Chemistry Laboratory

in the Subdiscipline Synopsis at the end of Subsection 3.5.5. More detailed descriptions are given in Appendix C.

3.5.2 Relativity and Gravitation

3.5.2.1 Screening for Space Research Applicability

Relativity and Gravitation must be considered under Classical Mechanics. Relativity, and Gravitation (Item 4.1.1 on Chart 4-2 in Appendix A) in the organized overview of Space Physics. This discipline was divided into three subheadings: Classical Mechanics (Item 4.1.1.1), Special Relativity (Item 4.1.1.2), and General Relativity (Item 4.1.1.3).

Questions were not developed under the Classical Mechanics subheadings for two reasons. First, the field of classical mechanics is well understood, and there seems to be no need to test it except as relativity theory affects its predictions. Second, guidelines received from NASA placed emphasis on relativity.

The second subheading, Special Relativity is considered to be well understood and is of little interest in the development of an experimental program.

Even a measurement of the velocity of light itself is no longer of basic importance, since a certain defined value is soon to be assigned by the International Congress of Standards. This assigned definition will satisfy all existing requirements of theory; it amounts, in effect, to redefining the standard meter in terms of the second.

As a consequence of these considerations, only those experiments dealing with general relativity have significance for an orbital research program. In this branch of Space Physics, there are three broad areas in which critical issues were derived: first, the validity of the principle of equivalence (equivalence of gravitational and inertial mass; second, the gross properties of the space-time continuum; and third, the identification of those aspects of the theory of relativistic gravitation that agree with observations.

3.5.2.2 Contributions of Ongoing Programs

The principle of equivalence is a basic foundation of relativistic gravitation theory. For test or point masses, the equivalence of inertial and gravitational mass has been demonstrated by Eotvos, and more recently by Dicke, to about one part in 10^{11}. Most relativistic gravitational theories therefore take this equivalence as a postulate. However, in theories other than that of Einstein (e.g., Brans-Dicke, Jordan, etc.), gravitational self-energy may produce a violation of this principle for finite-sized bodies. There are several possible techniques that may be used to search for the breakdown in the equivalence principle, all of them involving small unmanned satellites such as a satellite placed in a Jovian orbit. Thus, with the use of transponders and small automated satellites, testing of the validity of the equivalence principle seems quite feasible.

Experimentation addressed to the gross properties of the space-time continuum will be essentially concerned with remote sensing, since it involves searching for anisotropies and inhomogeneities in the universe at great distances. Experiments of this type are important because they relate directly to relativistic cosmology, but since without exception they involve remote sensing, they fall into the realm of Space Astronomy.

The third major area of relativistic gravitation is that of determining which theory is in closest agreement with the observations. Professor K. Thorne at the California Institute of Technology has pointed out that none of the possible theories of relativistic gravitation that physicists have been able to imagine contain more than nine independent parameters. Thus, a determination of which theory is most nearly correct requires measurements related to each of these parameters. Unfortunately, many of the proposed experiments repetitiously measure only a few of the parameters, and most of the parameters are not measured by any of the contemplated experiments.

Einstein's theory is favored by most theoreticians because of its elegance and relative simplicity. The whole variety of relativistic gravity theories are quite compatible with all of the local (i.e., solar system) measurements made to date. The basis for deciding among them will probably come from their cosmological and galactic-historical consequences, which are very different. Therefore, to evaluate any of these predicted consequences experimentally would be of great scientific importance, and the determination of even one of the ten parameters within about 1-percent error would be of great scientific interest. Furthermore, by past measurements (advance of Mercury's perihelion and light bending), it is known that there are real effects that are explainable only through the use of general relativity theory.

In this connection, tests of the bending of light in a gravitational field have been attacked with new vigor. Measurements of impressive accuracy have recently been made using such diverse techniques as daylight tracking of stars, long baseline radio telescope interferometry or pulsars, and tracking of radar transponders on unmanned probes (Mariners VI and VII).

The final area of investigation under General Relativity (Item 4.1.1.3) is the detection and study of gravitational waves. The experiments by Dr. Joseph Weber at the University of Maryland have shed some light on this subject, although some doubts still exist as to the explanation of his results. Dr. Weber has stated that he has detected gravitational radiation emanating from the galactic center. Theorists have pointed out, however, that the intensity measured for these waves suggests that 10^3 solar masses must be converted into gravitational waves every year, a loss of mass that would have been detected in its effects on galactic dynamics. In addition to this possible source, gravitational radiation from neutron stars and quasars has been predicted.

Measuring gravitational radiation is exceedingly difficult because of the small cross section for coupling these waves with laboratory-sized bodies.

Some doubt has been cast on the use of manned space research facilities for solving this problem. In essence, the major detection problem is the development of more sensitive electronics, rather than the elimination of background disturbances. In particular, the experimental detection limit is set by the thermal noise in the detector mass rather than by seismic or atmospheric fluctuations.

In summary, the 13 critical issues identified under relativity and gravitation were all rejected from further consideration, each for an appropriate reason, as described in the preceding discussion. Table 3-29 summarizes the analysis of these critical issues.

3.5.3 Cosmic Rays

The screening of the 25 critical issues derived in this subdiscipline is summarized in Table 3-30. Of the 25 critical issues, 7 fell into the area of high-energy particle physics (4.1.5.3), and 18 into galactic and extragalactic cosmic rays (4.2.1.3.3.2.2.). In deriving issues in the former area, only questions for which a space platform would apparently be useful were included. For example, many questions could be asked in neutrino physics, but experiments in this area gain no real advantage in being performed onboard a space vehicle, since the atmosphere absorbs a negligibly small fraction of the incoming neutrino flux. In the latter area, the questions derived did not undergo preliminary screening of this sort.

3.5.3.1 Screening for Space Research Applicability

For all the questions derived in the cosmic ray subdiscipline, there were in essence two properties of the space environment that were considered essential, viz., the absence of atmospheric attenuation and the possibility of long observation times. Many, if not all, of the experiments in this area could be performed from balloons or rockets (indeed, many of the investigations carried on thus far have been so performed), but the very limited observation times that these vehicles allow preclude, in many cases, the accumulation of statistically significant data. Thus the space research facility, with the extended observation times it affords, provides an excellent platform for the cosmic ray physics laboratory.

Only one characteristic of the space environment represents a possible problem in this experiment area, namely, background counts resulting from trapped radiation, particularly when the space vehicle passes through the South Atlantic anomaly. For a low-altitude orbit, however, the radiation background will not be a serious problem, i.e., many of the experiments can be run in a

Table- 3-29

SCREENING OF CRITICAL ISSUES FOR RELATIVITY AND GRAVITATION

Definition of Symbols:
E = Essential
H = Helpful
N = No Effect
T = Tolerable
I = Intolerable
U = Effects Unknown

	Space Research Selection Criteria														Manned Space Research Selection Criteria																				Relationship to Ongoing Programs			
	Orbital Characteristics				Space Environment Characteristics										Participation of Man										Flight Safety				Mission Performance Degradation							
															Scientist/ Observer				Development Engineer				Technician													
Critical Issue	Orbital Altitudes	Wide Spatial Coverage	Repeatable Spatial Positions	Relative Velocity	Long-Term Low Gravity	High Pumping Speed	Meteoroids	Plasma Conditions	Cosmic Radiation	Radiation Belts	Above the Atmosphere	Solar Radiation	Large Volume (No Wall Effects)	Critical Issue Suitable for Space Research (√) or Rejected for Reason R-__ *	Real-Time Data Analysis and Evaluation	Multiple Sensor Use	Sensor Mode or Parameter Selection	Cooperation with Principal Investigator on the Ground	Spacecraft Position or Orientation Selection	Sensor Operation and Parameter Variation	Evaluation of Sensor Design and Performance	Component Qualification Testing	Equipment Setup, Checkout, Maintenance, and Calibration	Servicing of Sensor/Equipment Consumables	External Environment Extremes (Radiation, Temperature, Vacuum, Etc)	Excessive Physiological Stress (Weightlessness, Fatigue, Dehydration, Etc)	Excessive Physiological Stress (Sensory Deprivation, Etc)	Crew Safety Effects (High voltage, Noise Level, Inflammables, Etc)	Acceleration Disturbances (Attitude Control/ Crew Mobility)	Effluent Release (Environmental Contamination)	Repetitive Duty Cycles (Continuous High Precision Observations)	Critical Issue Suitable for Manned Space Research (√)	Program on Which Preliminary Information has been (or is being) Developed	Program Completely Satisfying Experiment Requirements	Critical Issue Requirements Not Satisfied by Other Programs (√)	Critical Issue is Candidate for Future Manned Space Research (√√)
4.1.1.1.2.2.1 Obs of matter near Lagrangian points	N	N	N	N	N	N	N	N	N	N	N	N	N	R-7																						
4.1.1.1.2.2.2 Solar quadruple moment	N	N	N	N	N	N	N	N	N	N	H	N	N	R-7																						
4.1.1.3.1.1 Equivalence of inertial and gravitational mass	N	N	N	N	E	H	T	T	T	N	N	T	N	√	N	N	N	N	N	N	N	N	H	H	N	N	N	N	I	N	N					
4.1.1.3.2.1 Is space-time isotropic	N	N	N	N	N	N	N	N	N	N	E	N	N	R-8																						
4.1.1.3.3.1.1 Influence space curvature on planets	N	N	N	N	N	N	N	N	N	N	N	N	N	R-7																						
4.1.1.3.3.1.2 Precession of gyroscopes	N	N	N	N	E	H	N	N	N	N	N	N	N	√	H	N	N	H	N	N	H	N	H	H	N	N	N	N	I	T	N			Schiff-Fairbank Gyroscope Exp†		
4.1.1.3.3.1.3 Effect of gravitation on electromagnetic waves	N	N	N	N	N	N	N	N	N	N	N	N	N	R-7																						
4.1.1.3.3.2.1 Measurement of gravitational constant	N	N	N	N	E	E	T	T	T	T	N	N	N	√	N	N	N	N	N	N	N	N	H	H	N	N	N	N	I	N	N					
4.1.1.3.3.2.2 Determination of correct general relativity theory	N	N	N	N	N	N	N	N	N	N	E	N	N	R-7																						
4.1.1.3.3.2.3 Time dependence of gravitational forces	N	N	N	N	N	N	N	N	N	N	E	N	N	R-7																						
4.1.1.3.3.3.1 Detection of gravity waves	N	N	N	N	H	H	N	N	N	N	N	N	N	R-7																						
4.1.1.3.3.3.2 Properties of gravity waves	N	N	N	N	H	H	N	N	N	N	N	N	N	R-7																						
4.1.1.3.3.3.3 Origin of gravity waves	N	N	N	N	H	H	N	N	N	N	N	N	N	R-7																						

*R-7 Can be performed using ground based equipment and/or radar transponders on automated space probes.

R-8 Covered by Space Astronomy Discipline.

†Referenced on Page 3-168 of accompanying text.

FOLDOUT FRAME

FOLDOUT FRAME 2

Table 3-30

SCREENING OF CRITICAL ISSUES FOR COSMIC-RAY LABORATORY

Definition of Symbols:

E = Essential
H = Helpful
N = No Effect
T = Tolerable
I = Intolerable
U = Effects Unknown

		Space Research Selection Criteria: Orbital Characteristics				Space Environment Characteristics										Manned Space Research Selection Criteria: Participation of Man: Scientist/Observer				Development Engineer				Technician		Flight Safety				Mission Performance Degradation				Relationship to Ongoing Programs**			
	Critical Issue	Orbital Altitude	Wide Spatial Coverage	Repeatable Spatial Positions	Relative Velocity	Long-Term Low Gravity	High Pumping Speed	Meteoroids	Plasma Conditions	Cosmic Radiation	Radiation Belts	Above the Atmosphere	Solar Radiation	Large Volume (No Wall Effects)	Critical Issue Is Suitable for Space Research (√)	Real-Time Data Analysis and Evaluation	Multiple Sensor Use	Sensor Mode or Parameter Selection	Cooperation with Principal Investigator on the Ground	Spacecraft Position or Orientation Selection	Sensor Operation and Parameter Variation	Evaluation of Sensor Design and Performance	Component Qualification Testing	Equipment Setup, Checkout, Maintenance, and Calibration	Servicing of Sensor and Equipment Consumables	External Environmental Extremes (Radiation, Temperature, Vacuum, Etc)	Excessive Physiological Stress (Weightlessness, Fatigue, Dehydration, Etc)	Excessive Psychological Stress (Sensory Deprivation, Etc)	Affects Crew Safety (High Voltage, Noise Level, Inflammables, Etc)	Acceleration Disturbances (Attitude Control, Crew Mobility)	Effluent Release (Environmental Contamination)	Repetitive Duty Cycles (Continuous High Precision Observation)	Critical Issue Suitable for Manned Space Research (√)	Program on which Preliminary Information has been (or is being) Developed	Program Completely Satisfying Experiment Requirements	Experiment Requirements Not Satisfied by Other Programs (√)	Experiment is Candidate for Future Manned Space Research (√√)
4.1.5.3.6.1.1	What are the total p-p, p-n, and n-n cross sections at high energies?	N	N	N	N	N	H	N	N	E	T	H	T	N	√	H	E	E	E	N	E	E	H	E	E	N	N	N	T	N	N	N	√			√	√√
4.1.5.3.6.1.2	What are the differential p-p, p-n, and n-n cross sections at high energies?	N	N	N	N	N	H	N	N	E	T	H	T	N	√	H	E	E	E	N	E	E	H	E	E	N	N	N	T	N	N	N	√			√	√√
4.1.5.3.6.1.3	What are the angular and energy distributions of secondaries produced as a function of incoming proton and alpha-particle energies?	N	N	N	N	N	H	N	N	E	T	E	T	N	√	H	E	E	E	N	E	E	H	E	E	N	N	N	T	N	N	N	√			√	√√
4.1.5.3.6.2.1	What are the spallation cross sections of heavy nuclei on hydrogen?	N	N	N	N	N	H	N	N	E	T	H	T	N	√	H	E	E	E	N	E	E	H	E	E	N	N	N	T	N	N	N	√			√	√√
4.1.5.3.6.2.2	What is the multiplicity of charged-particle production from nuclear-spallation reactions?	N	N	N	N	N	H	N	N	E	T	H	T	N	√	H	E	E	E	N	E	E	H	E	E	N	N	N	T	N	N	N	√			√	√√
4.1.5.3.6.2.3	What is the energy distribution of the outgoing particles from nuclear-spallation reactions?	N	N	N	N	N	H	N	N	E	T	H	T	N	√	H	E	E	E	N	E	E	H	E	E	N	N	N	T	N	N	N	√			√	√√
4.1.5.3.6.2.4	What is the angular distribution of the outgoing particles from nuclear-spallation reactions?	N	N	N	N	N	H	N	N	E	T	H	T	N	√	H	E	E	E	N	E	E	H	E	E	N	N	N	T	N	N	N	√			√	√√
4.2.1.3.3.2.2.1.1.1	What is the electron-positron ratio in the primary cosmic radiation as a function of energy?	N	H	N	N	N	H	N	N	E	T	E	T	N	√	H	E	E	E	H	E	E	H	E	E	N	N	N	T	N	N	N	√			√	√√
4.2.1.3.3.2.2.1.2.1	What is the abundance of the low-mass isotopes present in high energy cosmic radiation?	N	H	N	N	N	H	N	N	E	T	E	T	N	√	H	E	E	E	N	E	E	H	E	E	N	N	N	T	N	N	N	√			√	√√
4.2.1.3.3.2.2.1.2.2	What is the charge composition as a function of energy of the primary cosmic radiation?	N	H	N	N	N	H	N	N	E	T	E	T	N	√	H	E	E	E	N	E	E	H	E	E	N	N	N	T	N	N	N	√			√	√√
4.2.1.3.3.2.2.1.3.1	Are any anti-protons or anti-nuclei present in the primary cosmic rays?	N	N	N	N	N	H	N	N	E	T	E	T	N	√	N	E	H	H	N	E	E	H	E	E	N	N	N	T	N	N	N	√			√	√√
4.2.1.3.3.2.2.1.3.2	Are there any long-lived heavy isotopes present in the cosmic rays?	N	N	H	N	N	H	N	N	E	N	E	N	N	√	N	E	H	H	N	E	E	H	E	E	N	N	N	T	N	N	N	√			√	√√
4.2.1.3.3.2.2.1.3.3	Are any stable neutron-rich transuranic elements present in the cosmic radiation?	N	N	H	N	N	H	N	N	E	N	E	N	N	√	N	E	H	H	N	E	E	H	E	E	N	N	N	T	N	N	N	√			√	√√
4.2.1.3.3.2.2.1.3.4	Are there any stable fractionally charged particles present in the primary cosmic rays?	N	N	N	N	N	H	N	U	E	U	E	T	N	√	H	E	H	H	N	E	E	H	E	E	N	N	N	T	N	N	N	√			√	√√
4.2.1.3.3.2.2.1.3.5	Are there any particles in the cosmic rays with properties yet unknown?	N	H	U	N	N	H	N	U	E	U	E	U	N	√	H	H	H	H	H	H	H	H	E	E	N	N	N	T	N	N	N	√			√	√√
4.2.1.3.3.2.2.2.1	What is the energy spectrum of gamma radiation present in the primary cosmic-ray flux?	N	E	H	N	N	H	N	N	E	T	E	T	N	√	H	E	E	E	H	E	E	H	E	E	N	N	N	T	N	N	N	√			√	√√
4.2.1.3.3.2.2.2.2	What is the energy spectrum of the heavy nuclei in the primary cosmic radiation?	N	H	N	N	N	H	N	N	E	T	E	T	N	√	H	E	E	E	N	E	E	H	E	E	N	N	N	T	N	N	N	√			√	√√
4.2.1.3.3.2.2.2.3	What is the energy spectrum of the primary electrons in the cosmic rays?	N	H	N	N	N	H	N	N	E	T	E	T	N	√	H	E	E	E	H	E	E	H	E	E	N	N	N	T	N	N	N	√			√	√√
4.2.1.3.3.2.2.2.4	What is the energy spectrum of protons in the primary cosmic rays?	N	E	N	N	N	E	N	N	E	T	E	T	N	√	H	E	E	E	N	E	E	H	E	E	N	N	N	T	N	N	N	√			√	√√
4.2.1.3.3.2.2.2.5	What is the energy spectrum of the light nuclei in the primary cosmic radiation?	N	H	N	N	N	H	N	N	E	T	E	T	N	√	H	E	E	E	N	E	E	H	E	E	N	N	N	T	N	N	N	√			√	√√
4.2.1.3.3.2.2.3.1	What temporal fluctuations are present in the nuclear component of the primary cosmic-ray flux?	N	H	N	N	N	H	N	N	E	T	E	T	N	√	H	E	E	E	N	E	E	H	E	E	N	N	N	T	H	N	N	√			√	√√
4.2.1.3.3.2.2.3.2	What is the spatial and temporal distribution of electrons in the primary cosmic-ray flux?	N	H	N	N	N	H	N	N	E	T	E	T	N	√	H	E	E	E	H	E	E	H	E	E	N	N	N	T	N	N	N	√			√	√√
4.2.1.3.3.2.2.3.3	What is the spatial and temporal distribution of gamma rays in the primary cosmic-ray flux?	N	E	H	N	N	H	N	N	E	T	E	T	N	√	H	E	E	E	N	E	E	H	E	E	N	N	N	T	N	N	N	√			√	√√
4.2.1.3.3.2.2.3.4	What is the degree of anistropy present in the nuclear component of the cosmic ray flux?	N	H	N	N	N	H	N	N	E	T	E	T	N	√	H	E	E	E	N	E	E	H	E	E	N	N	N	T	N	N	N	√			√	√√
4.2.1.3.3.2.2.3.5	What are the characteristics of the albedo particles above 100 MeV?	N	H	N	N	N	H	N	U	E	U	E	U	N	√	N	E	H	E	H	E	E	H	E	E	N	N	N	T	N	N	N	√	Several		√	√√

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standby mode during passage through the anomaly and otherwise will be unaffected by this source. Another possible source of background radiation is the sun. During periods of intense solar activity, particularly in the event of a relativistic solar flare, the experiments must again be placed in a standby mode. These events are rare and do not represent a real problem.

Thus, all 25 critical issues were deemed suitable to space (Column 14, Table 3-30).

3.5.3.2 Consideration of Manned Space Research Applicability

The necessity of man in the cosmic ray research area is based on the laboratory concept discussed below. Without his presence, any of the experiments could undoubtedly be performed, but the equipment could not be serviced (or more importantly, reconfigured for another investigation) when enough data had been collected. The versatility of the facility is the primary reason for its existence as a laboratory. To achieve this versatility, man is essential. Thus, all 25 critical issues were also deemed suitable to manned space research (Column 32, Table 3-30).

3.5.3.3 Contributions of Ongoing Programs

All of the critical issues derived in the cosmic ray physics subdiscipline have been partially answered by a variety of other programs. On the other hand, complete answers to the critical issues will probably be never completely determined. Rather, newer and more refined measurements will continue to advance our knowledge. Taking this point of view, questions were not screened out as being answered by another program, but rather experimental techniques already proven successful in other programs were screened out. More sophisticated equipment is proposed for the manned program to continue the experimental program that has long been underway in this area.

Descriptions of the past research and current status of each of the questions is included in the synopsis. The experiments program proposed did not include the Skylab or HEAO experiments as ongoing programs, but only past and present spacecraft, balloon, and rocket programs.

3.5.3.4 Clustering of Critical Issues

The critical issues in the cosmic ray area were grouped into the following ten research clusters.

Cluster No.	Title
4-CR-1	Charge and Energy Spectra of Cosmic Ray Nuclear Component
4-CR-2	Energy Spectrum of High-Energy Primary Electrons and Positrons
4-CR-3	Energy Spectrum and Spatial Distribution of Primary Gamma Rays
4-CR-4	Long-Lived Heavy Isotopes in Cosmic Rays
4-CR-5	Antinuclei in Cosmic Rays
4-CR-6	Quarks (Stable Fractionally Charged Particles) in Cosmic Rays
4-CR-7	Unknown Particles in Cosmic Rays
4-CR-8	Characteristics of Albedo Particles Above 100 Mev
4-CR-9	Nucleon-Nucleon Cross Sections at High Energies
4-CR-10	Spallation Cross Sections at High Energies

In the first eight clusters, the properties of the incoming cosmic radiation are studied, while in the last two, the incoming radiation is used as a beam source to conduct experiments in high-energy physics. In the latter area, all the particle physics experiments were included under 4-CR-9, Nucleon-Nucleon Cross Sections, while the area of spallations and nuclear fragmentation was included in 4-CR-10. However, it should be noted that two of the particles being searched for in the primary radiation, quarks (4-CR-6) and magnetic monopoles (4-CR-7), might also be produced in the high-energy interactions studied in 4-CR-9 and are thus implicitly a part of this research cluster.

With the exception of 4-CR-3, Primary Gamma Rays, none of these research clusters require high pointing accuracy; they require only a knowledge of the space vehicle's angular orientation for a possible correlation of counting rate with direction. Cluster 4-CR-3 is the study of gamma ray astronomy and, as such, requires pointing accuracies of the same order as does x-ray astronomy. It should be noted that only the high-energy gamma ray portion of the electromagnetic spectrum is being studied as a part of cosmic ray physics; the lower-energy portions of the spectrum are being investigated as part of Space Astronomy. This division is quite natural on the basis of experimental techniques and equipment.

The facility defined for the other cosmic ray clusters is easily reconfigured for the study of high-energy gamma rays; that is, the techniques for detecting this radiation are those of particle detection and counting that are normally used in a cosmic ray experiment.

3.5.3.4 Laboratory Concept

The derivation of the laboratory concept for cosmic ray studies is based on two principles: first, that the equipment required for all the experiments consists of a basic set of detectors and electronics that can be configured in various ways for performing the different experiments; and second, that the actual experiments that will be performed cannot at this time be defined in detail, but only in concept, and the facility should therefore be capable of satisfying a broad range of experimental objectives.

Experiments in either high-energy cosmic-ray astrophysics or interaction physics are extremely complex, and any of them could employ perhaps as many as 100 separate detectors of many different types. To obtain an "answer" to a given critical issue will, in general, require many different experimental geometries, as well as the simultaneous measurement of certain parameters per experiment. Moreover, the measurement of a given parameter in one experiment is almost completely unrelated to that same parameter as required in a different experiment, because these parameters are physical properties of individual cosmic ray events. For example, consider the critical issue, "What is the charge composition as a function of energy of nuclear primary cosmic radiation?" Any particular experiment designed to provide such information would be restricted to a given charge interval and a given energy interval. To investigate another portion of either the charge or energy spectrum would, in general, involve a different experimental setup with (perhaps) different detectors, different geometries, and different resolution capabilities. In addition, even after restricting the charge and energy ranges for a given experiment, the experiment itself is still not fully defined. Nevertheless, certain major items of basic instrumentation and data handling systems are necessary, and maximum flexibility should be incorporated into the laboratory design to allow configuring this instrumentation into the required experimental setups.

Thus the cosmic ray laboratory was defined by providing an experiment description for the laboratory as a whole, including all the requirements placed on the space vehicle and the crew, with the ten research clusters being represented by (1) research objectives and current status, and (2) a particular example of a possible experimental setup for performing the required measurements in that cluster.

3.5.3.5 Brief Descriptions of the Research Clusters

In summary, in the subdiscipline of cosmic rays, 10 research clusters were formed from the 25 critical issues judged to be suitable for a manned earth-orbital research program. A brief description of the research is presented at the end of Subsection 3.5. More detailed descriptions are given in Appendix C.

3.5.4 Plasma Physics

In many respects, the plasma physics area presents a more complex problem to the experiment planner than the other areas in Space Physics if the orbit is left as an open ended parameter. Although such general questions as "What is the electron temperature?" have been formulated, the immense variability in plasma parameters that can be encountered over possible orbits tends to preclude any generalization in terms of experimental techniques and facilities. Conversely, the experimental study of a specific question such as "Is a given field line open or closed?" requires a specific vehicle orbit. Additionally, almost all of the low-energy plasma physics experiments and measurements will not be performed in the space vehicle, but rather from the vehicle and in the medium.

A first requirement of the plasma physics effort must be a study of the spatial extent of the region perturbed by the space research facility throughout its orbit. The introduction of any object into a plasma, whether in a terrestrial laboratory or in space, will produce a major perturbation in the plasma characteristics in the immediate vicinity of the object. For this reason, the perturbation caused by a space research facility may seriously handicap or even preclude the experimental study of a large class of plasma physics questions identified in this study. Experiments affected in this way would include the long-term study of environmental characteristics, such as electron density, electron temperature, ion temperature, ion species, and electric and magnetic fields, in the region of the vehicle orbit. A detailed knowledge of these parameters is required for performing any basic low-energy plasma physics experiment. This investigation represents the first research area in the plasma physics area. The above measurement limitation does not extend to experiments based on higher energies, high power levels, or remote observations where local effects are unimportant, because these questions in general relate to magnetospheric and ionospheric physics, which require active perturbation of the environment. The screening of the critical issues for plasma physics is summarized in Table 3-31.

3.5.4.1 Screening for Space Applicability

Screening for space applicability in the plasma physics area was minimal because the questions developed were primarily directed towards an understanding of the space environment itself. Emphasis was placed on questions related to the local space environment rather than to all of space. For example, questions related to the transition region or the interplanetary plasma were, for the most part, not included. This reflected a policy adopted at the outset that we would consider only earth-orbital experimentation. Nonetheless, a few questions were included that were later screened as not meeting this requirement, for example 4.1.6.3.2.1, an earth-bound laboratory question, or 4.1.6.4.3.3.3, a solar plasma question.

3.5.4.2 Manned Space Flight Applicability

In testing for manned space flight applicability, it was often difficult to determine if a given individual question could be answered by the unmanned experiment approach. Many of the questions are quite complex and will require many measurements under different plasma conditions before an answer can be obtained. Indeed many questions could require a program in themselves to obtain a satisfactory answer, as, for example, 4.2.12.1.3.5.4, "What is the lifetime of an ion in the magnetospheric electrons?" Rather than testing individual questions for manned research applicability, then, a laboratory concept was used in this subdiscipline. That is, a broad experiment approach was used which could provide answers to a great many questions simultaneously. Such an approach would require a man for, as a minimum, experiment set-up, check-out, and coordination. Some of the derived questions could not be answered completely from a manned laboratory because they require too many hours in an intolerable radiation environment or too many repetitious measurements. These questions might well be approached with an automated satellite, or possibly, with a subsatellite controlled from the space platform.

3.5.4.3 Contributions of Ongoing Programs

Many past or current programs include experiments that attempt to answer most of the questions derived in this study. However, these experiments only provide, at best, partial answers. More often than not, new questions are raised by each series of measurements. The Explorer and OGO series, VELA, ATS, ISIS, and a long list of sounding rockets have all helped to shed light on the questions derived here. None of the questions have been answered, however. Indeed, these questions represent an attempt to define the near-earth space environment and the processes that are occurring there. The production, energization, diffusion, and eventual loss of plasma and energetic particles are processes that will probably never be completely understood. Certainly no completed or currently planned program will provide this understanding.

3.5.4.4 Establishment of Research Clusters

The establishment of research clusters in the plasma physics area was based on two principles: first, provision of a fundamental description of the overall research objectives toward which the plasma physics laboratory on the manned space research facility should be directed, and second, inclusion of all the experimental techniques that can be used to meet these objectives. A reasonable arrangement that fits these requirements falls into two areas:

1. Spacecraft-environment interaction.
2. Structure and processes of the space environment.

Area 2 can be further divided into three investigations:

2.1 Energetic particle dynamics in the magnetosphere.

2.2 Thermal plasma in the ionosphere and magnetosphere.

2.3 Auroral processes.

Table 3-31

SCREENING OF CRITICAL ISSUES FOR PLASMA PHYSICS

Definition of Symbols:
- E = Essential
- H = Helpful
- N = No effect
- T = Tolerable
- I = Intolerable
- U = Effects unknown

		Space Research Selection Criteria														Manned Space Research Selection Criteria																		Relationship to Ongoing Programs (see Note 2)			
		Earth Orbital Characteristics				Space Environment Characteristics										Participation of Man: Scientist/Observer				Development and Operations Engineer				Technician		Flight Safety				Mission Performance Degradation							
	Critical Issue	Orbital Altitudes	Wide Spatial Coverage	Repeatable Spatial Positions	Relative Velocity	Long-Term Low Gravity	High Pumping Speed	Meteoroids	Plasma Conditions	Cosmic Radiation	Radiation Belts	Above the Atmosphere	Solar Radiation	Large Vacuum Volume (No Wall Effects)	Critical Issue Suitable for Space (✓)	Real-Time Data Analysis and Evaluation	Multiple Sensor Use	Sensor Mode or Parameter Selection	Cooperation with Principal Investigator on the Ground	Spacecraft Position or Orientation Selection	Sensor Operation and Parameter Variation	Evaluation of Sensor Design and Performance	Component Qualification Testing	Equipment Setup, Checkout, Maintenance, and Calibration	Servicing of Sensor and Equipment Consumables	External Environmental Extremes (see Notes 1 and 4) (Radiation, Temperature, Vacuum, etc.)	Excessive Physiological Stress (Weightlessness, Fatigue, Dehydration, etc.)	Excessive Physiological Stress (Sensor Deprivation, Etc.)	Crew Safety Effects (High Voltage, Noise Level, Inflammables, etc.)	Acceleration Disturbances (Attitude Control, Crew Mobility)	Effluent Release (Environmental Contamination)	Repetitive Duty Cycles (Continuous High Precision Observations) (See Note 2)	Critical Issue Suitable for Manned Space Flight (✓) (See Note 3)	Program on Which Preliminary Information Has Been (or is Being) Developed	Program Completely Satisfying Experiment Requirements	Experiment Requirements Not Satisfied by Other Programs (✓)	Experiment is Candidate for Future Manned Space Flight (✓✓)
4.1.5.2.5.3.1	How can electron-beam accelerators in orbit simulate geophysical phenomena?	E	E	H	T	N	H	T	E	T	H	E	N	N	✓	H	H	H	H	H	H	H	N	F	E	T	N	N	T	N	U	N	✓			✓	✓✓
4.1.6.3.1.1.1	How do magnetospheric observations correlate with laboratory mirror experiments?	E	E	H	T	N	N	T	E	T	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓	Explorer, Imp, OGO		✓	✓✓
4.1.6.3.1.1.2	Are end-plate losses analogous to auroral precipitation?	E	E	H	T	N	N	T	E	T	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓	Explorer, Injun		✓	✓✓
4.1.6.3.1.1.3	Are space superthermal particles produced similar to lab energetic particles?	E	E	H	T	N	N	T	E	T	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓	Explorer		✓	✓✓
4.1.6.3.2.1	Howare Terrella and bow-shock experiments related?	N	N	N	N	N	N	N	N	N	N	N	N	N																							
4.1.6.4.3.2.1	Can long wavelengths in space be used to study plasma waves?	E	H	H	T	N	N	T	E	T	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	H	T	✓			✓	✓✓
4.1.6.4.3.2.2	Can Alfven waves be propagated in the magnetosphere?	E	H	H	T	N	N	T	E	T	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓			✓	✓✓
4.1.6.4.3.2.3	Can whistler mode experiments be performed in the magnetosphere?	E	H	H	T	N	N	T	E	T	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓	OGO, ISIS		✓	✓✓
4.1.6.4.3.2.4	Can drift waves be studied in the magnetosphere?	E	H	H	T	N	N	T	E	T	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓			✓	✓✓
4.1.6.4.3.2.5	Can non-linear waves be generated along lines of force?	E	H	H	T	N	N	N	E	N	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	I	N	N	N	N	U	T	✓			✓	✓✓
4.1.6.4.3.2.6	Is bowshock similar to laboratory collisionless shocks?	E	H	H	T	N	N	N	E	T	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	I	N	N	N	N	U	T	✓	Explorer		✓	✓✓
4.1.6.4.3.3.1	Can magnetosphere be used to study deflection of E-M waves?	E	H	H	T	N	N	N	E	T	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓	Mariner		✓	✓✓
4.1.6.4.3.3.3	Can plasma effect near sun cause E-M wave bending?	I	H	H	T	N	N	N	E	T	E	H	E	E																				Imp, Pioneer			
4.1.6.4.3.3.4	How does fluctuating plasma impact magnetic field? Is there drag?	I	H	H	T	N	N	N	E	T	E	E	E	E																				Imp, Pioneer			
4.2.1.2.1.3.3.1	How does ionosphere affect H and He balance in atmosphere?	E	E	H	T	N	N	N	E	N	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	N	N	N	N	N	U	T	✓			✓	✓✓
4.2.1.2.1.3.4.1.1	What is the vector magnetic field in the ionosphere?	E	E	H	T	N	N	N	E	N	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	N	N	N	N	N	U	I	✓			✓	✓✓
4.2.1.2.1.3.4.1.1.1	Are field lines in the polar region open or closed?	E	H	H	N	N	N	N	E	T	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	N	N	N	N	N	U	T	✓			✓	✓✓
4.2.1.2.1.3.4.1.1.2	Can conjugate points be determined to 1 km or better?	H	E	H	T	N	N	N	E	N	E	H	T	E	✓	H	H	H	H	H	N	H	N	H	H	N	N	N	N	N	U	T	✓	ATS		✓	✓✓
4.2.1.2.1.3.4.1.1.3	Are there diurnal or seasonal variations in conjugate points?	H	E	E	N	N	N	N	E	N	E	H	E	E	✓	H	H	H	H	H	N	H	N	H	H	N	N	N	N	N	U	I	✓	ATS		✓	✓✓
4.2.1.2.1.3.4.1.2	What is the electron density in the ionosphere?	E	E	E	T	N	N	T	E	T	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	N	N	N	N	N	U	I	✓	Explorer, sounding rockets		✓	✓✓
4.2.1.2.1.3.4.1.3	What ionic species are present in the ionosphere?	E	E	E	N	N	N	T	E	T	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	N	N	N	N	N	U	I	✓	Explorer, sounding rockets		✓	✓✓
4.2.1.2.1.3.4.1.3.1	What is density of each ionic species in the ionosphere?	E	E	E	T	N	N	T	E	T	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	N	N	N	N	N	U	I	✓	Explorer, sounding rockets		✓	✓✓
4.2.1.2.1.3.4.1.3.2	What is temperature of each ionic species in the ionosphere?	E	E	E	T	H	N	T	E	T	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	N	N	N	N	N	U	I	✓	Explorer, sounding rockets		✓	✓✓
4.2.1.2.1.3.4.1.4	What is electron temperature in the ionosphere?	E	E	E	T	N	N	T	E	T	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	N	N	N	N	N	U	I	✓	Explorer, sounding rockets		✓	✓✓
4.2.1.2.1.3.4.1.5	What waves are present in the ionosphere?	E	E	E	T	N	N	N	E	T	E	E	T	E	✓	H	H	H	H	H	H	H	N	H	H	N	N	N	N	N	U	T	✓			✓	✓✓
4.2.1.2.1.3.4.1.5.1	What effect does incoherent Cerenkov radiation have on ionospheric emissions?	E	H	H	T	N	N	N	E	N	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	N	N	N	N	N	U	T	✓			✓	✓✓
4.2.1.2.1.3.4.1.5.2	How do VLF waves interact with particles in the ionosphere and magnetosphere?	E	E	E	T	N	N	N	E	T	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	N	N	N	N	N	U	T	✓	ISIS, OGO		✓	✓✓
4.2.1.2.1.3.4.1.5.3	How are VLF waves transmitted through the upper ionosphere?	E	H	E	T	N	N	N	E	T	E	H	I	E	✓	H	H	H	H	H	N	H	N	H	H	N	N	N	N	N	U	T	✓	ISIS		✓	✓✓
4.2.1.2.1.3.4.1.5.4	Study of effects of artificially produced VLF waves.	E	E	E	T	N	N	T	E	T	E	H	T	E	✓	H	H	H	H	H	N	H	N	H	H	N	N	N	N	N	U	T	✓	ATS		✓	✓✓
4.2.1.2.1.3.4.2.1	Can chemical releases perturb ionospheric characteristics?	H	H	H	N	N	N	T	E	T	N	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	N	N	N	I	N	U	T	✓	Sounding rockets		✓	✓✓
4.2.1.2.1.3.4.2.1.1	What is luminous efficiency of ion beams in upper atmosphere?	H	H	H	N	N	N	T	E	T	N	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	N	N	N	T	N	U	T	✓			✓	✓✓
4.2.1.2.1.3.4.2.2	What are consequences of irradiating the ionosphere with high intensity E-M waves?	H	N	H	N	N	N	N	E	T	E	H	T	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓			✓	✓✓
4.2.1.2.1.3.4.2.2.1	What RF power and frequencies are required to substantially heat ionosphere?	H	H	H	N	N	N	N	E	N	E	H	H	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	T	N	U	T	✓			✓	✓✓
4.2.1.2.1.3.4.2.3	Can electron densities be enhanced so as to trigger aurora?	E	N	E	N	N	N	N	E	N	E	E	H	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	T	N	U	T	✓			✓	✓✓
4.2.1.2.1.3.4.2.4	What are the processes determining the production and loss of ionospheric plasma?	E	E	E	N	N	N	T	E	T	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	N	N	N	N	N	U	T	✓	Explorer, sounding rockets		✓	✓✓
4.2.1.2.1.3.4.2.5	Can proton injection cause aurora? How can one relate artificial to natural aurora?	E	H	H	N	N	N	N	E	N	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	T	N	U	T	✓			✓	✓✓
4.2.1.2.1.3.5.1	Are energetic particles in the Earth's magnetosphere solar or terrestrial in origin?	E	E	H	T	N	N	T	E	T	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	I	N	N	T	N	U	T	✓	Explorer		✓	✓✓
4.2.1.2.1.3.5.1.1	Does magnetic field annihilation occur in the magnetospheric tail?	E	E	E	T	N	N	N	E	T	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	I	N	N	N	N	U	T	✓	OGO, Imp		✓	✓✓
4.2.1.2.1.3.5.1.2	Where does solar wind enter magnetosphere and how does it flow toward Earth?	E	E	E	T	N	N	N	E	T	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	I	N	N	N	N	U	T	✓	Imp, OGO, Vela		✓	✓✓
4.2.1.2.1.3.5.1.2.1	What are the plasma-flow characteristics in specific regions of the magnetosphere?	E	E	E	I	N	N	N	E	F	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	I	N	N	N	N	U	T	✓	Imp, OGO, Vela		✓	✓✓
4.2.1.2.1.3.5.1.3	Does natural injection from the interplanetary medium occur into magnetosphere?	E	T	N	N	N	N	T	E	T	E	E	N	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓			✓	✓✓
4.2.1.2.1.3.5.1.4	Can tracer elements show gain and loss processes?	E	E	E	N	N	N	I	E	T	E	E	H	E	✓	H	H	H	H	H	N	H	N	H	H	N	N	N	T	N	U	T	✓	Sounding rockets		✓	✓✓
4.2.1.2.1.3.5.2	How can magnetosphere be investigated by low intensity beams?	E	H	H	T	N	N	N	E	T	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	T	N	U	T	✓			✓	✓✓
4.2.1.2.1.3.5.2.1	Can electron, proton, or plasma beams enhance natural magnetospheric instability?	E	E	H	N	N	N	N	E	T	E	E	H	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	I	N	U	T	✓	Sounding rockets		✓	✓✓
4.2.1.2.1.3.5.2.2	What conditions does magnetosphere impose on a diagnostic particle beam?	E	E	H	T	N	N	N	E	T	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓			✓	✓✓
4.2.1.2.1.3.5.3	What information can be derived from various detonations in magnetosphere?	E	E	E	N	N	N	T	E	N	E	E	H	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓	Sounding rockets		✓	✓✓
4.2.1.2.1.3.5.3.1	Can a Barium release determine structure of magnetospheric field lines?	E	H	N	T	N	N	N	E	N	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	T	N	U	T	✓	Sounding rockets		✓	✓✓
4.2.1.2.1.3.5.3.1.1	What is the geometry of magnetic field lines at specific points in space?	E	H	E	T	N	N	N	E	N	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	I	N	N	N	N	U	I	✓			✓	✓✓
4.2.1.2.1.3.5.3.1.2	How can field line geometry be measured?	E	H	H	T	N	N	N	E	N	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	N	N	N	N	N	U	T	✓			✓	✓✓
4.2.1.2.1.3.5.3.1.3	What is geometry of electric field lines at same points in space?	E	E	H	T	N	N	N	E	N	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	I	N	N	N	N	U	I	✓			✓	✓✓
4.2.1.2.1.3.5.3.1.4	How can electric field lines be measured?	E	H	H	T	N	N	N	E	N	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	N	N	N	N	N	U	T	✓			✓	✓✓
4.2.1.2.1.3.5.4	What is the lifetime of an ion in the magnetosphere?	E	H	E	N	N	N	T	E	H	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓			✓	✓✓
4.2.1.2.1.3.5.4.1	Is tearing mode active in the magnetospheric tail? Is there a merging rate?	E	H	E	N	N	N	T	E	N	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	I	N	N	N	N	U	T	✓	OGO		✓	✓✓
4.2.1.2.1.3.5.4.2	Are flute instabilities active in magnetosphere? Other losses and instabilities?	E	H	H	T	N	N	N	E	N	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓	OGO		✓	✓✓
4.2.1.2.1.3.5.4.3	Can electric fields parallel to magnetic fields exist in the magnetosphere?	E	H	H	T	N	N	N	E	N	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓			✓	✓✓
4.2.1.2.1.3.5.4.3.1	What is the conductivity along the magnetic lines of force?	E	H	E	T	N	N	T	E	T	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓			✓	✓✓
4.2.1.2.1.3.5.4.4	Do non-dipole fields cause instabilities in the magnetosphere?	E	H	H	N	N	N	N	E	T	E	E	I	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓			✓	✓✓
4.2.1.2.1.3.5.4.5	What are the fluctuating electric and magnetic fields in the magnetosphere?	E	H	H	T	N	N	T	E	T	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓	OGO, ATS		✓	✓✓
4.2.1.2.1.3.5.4.5.1	What is the nature of transient fluctuations of E-M fields and electron populations?	E	E	H	N	N	N	T	E	T	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓	OGO, ATS		✓	✓✓
4.2.1.2.1.3.5.4.5.2	What is the state of order among electron populations in the magnetosphere?	E	E	H	N	N	N	I	E	T	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	I	N	N	N	N	U	I	✓	OGO, ATS, Explorer		✓	✓✓
4.2.1.2.1.3.5.4.6	What is rate of Bohm diffusion in the magnetosphere?	E	E	E	N	N	N	N	E	T	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓			✓	✓✓
4.2.1.2.1.3.5.4.6.1	What drives radial diffusion of trapped magnetospheric electrons?	E	H	E	T	N	N	N	E	T	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	I	N	N	N	N	U	T	✓	Explorer		✓	✓✓
4.2.1.2.1.3.5.5	What waves can propagate in the magnetosphere?	E	E	E	T	N	N	T	E	T	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓	OGO, ATS, ISIS		✓	✓✓
4.2.1.2.1.3.5.5.1	What are the dispersion relations in the magnetosphere?	E	E	E	T	N	N	I	E	H	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓	OGO, ATS, ISIS		✓	✓✓
4.2.1.2.1.3.5.5.2	Can trapped particles be accelerated by E-M radiation?	E	H	E	N	N	N	N	E	T	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓			✓	✓✓
4.2.1.2.1.3.5.5.2.1	What radiation power is needed to reduce radiation exposure of astronauts?	E	N	H	N	N	N	N	E	T	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓			✓	✓✓
4.2.1.2.1.3.5.5.3	Can ion cyclotron propagation experiments be performed in the magnetosphere?	E	H	H	T	N	N	N	E	F	E	E	T	E	✓	H	H	H	H	H	N	H	N	H	H	N	N	N	N	N	H	T	✓	ISIS		✓	✓✓
4.2.1.2.1.3.5.6	Are striations a characteristic of space? Is Simon theory valid?	E	H	H	N	N	N	I	E	T	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	N	N	N	N	N	H	T	✓			✓	✓✓
4.3.1.1.3	What is the effect of spacecraft potential on wake?	E	N	H	H	N	N	N	E	E	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	I	N	N	N	N	U	T	✓	Explorers, Gemini, Ariel		✓	✓✓
4.3.1.1.[illegible]	What is the effect of leakage and outgassing on space environment?	E	N	H	H	N	H	N	E	F	E	E	E	[illegible]	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	H	T	✓			✓	✓✓
4.3.1.1.[illegible]	How are particle measurements influenced by satellite environment?	E	N	H	H	N	N	N	E	E	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	H	T	✓			✓	✓✓
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	✓			✓	✓✓
4.3.1.2.4	How do plasma and ion propulsion devices interact with environment?	E	N	H	H	N	E	N	E	T	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓			✓	✓✓
4.3.1.2.5	What factors affect vehicle drag characteristics?	E	N	H	E	N	N	N	T	T	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓	Reentry Rockets		✓	✓✓
4.3.2.1.1	What is the lowest achievable vacuum near the spacecraft?	E	N	H	E	N	E	N	E	T	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	E	T	✓	Explorers, Gemini, Ariel		✓	✓✓
4.3.2.1.2	How does the spacecraft wake affect environmental measurements?	E	N	H	E	N	E	N	E	E	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	E	T	✓	Explorers, Gemini, Ariel		✓	✓✓
4.3.2.1.3	What is the effect of vehicle size and shape on wake?	E	N	H	E	N	N	N	E	N	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	E	T	✓	Explorers, Gemini, Ariel		✓	✓✓
4.3.2.1.4	How do high-power antennas affect the wake?	E	N	H	H	N	N	N	E	T	E	N	E	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓			✓	✓✓
4.3.2.1.5	Are waves produced in the wake?	E	N	H	H	N	N	N	E	N	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓	Reentry Rockets		✓	✓✓
4.3.2.1.6	How can subsatellites be used to measure the wake?	E	H	H	N	N	N	T	E	T	E	E	E	E	✓	E	H	H	H	H	N	H	N	E	E	T	N	N	N	N	E	T	✓			✓	✓✓
4.3.2.1.7	What is electric field distribution in the wake?	E	N	H	E	N	N	N	E	N	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	E	T	✓			✓	✓✓
4.3.2.1.8	How does the magnetic field affect the wake?	E	H	H	E	N	N	N	E	N	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓	Reentry Rockets		✓	✓✓
4.3.2.1.9	How will VLF antennas affect the wake?	E	N	H	H	N	N	N	E	N	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓			✓	✓✓
4.3.2.2.1	What is the temperature near the spacecraft?	E	H	H	E	N	N	N	E	N	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓	Explorers, Gemini, Ariel		✓	✓✓
4.3.2.2.4	How does solar UV affect spacecraft potential	E	N	H	N	N	N	N	E	E	E	E	E	E	✓	H	H	H	H	H	N	H	N	H	H	T	N	N	N	N	U	T	✓	Explorers, Gemini, Ariel		✓	✓✓

Notes:
1. I's given on the basis of prolonged measurements in radiation belts, or at high L values > 6.
2. ✓'s given even in case of I's because useful data may be obtained by manned mission even if full question cannot be answered by such a mission.
3. It is of utmost priority to determine which plasma measurements can be made from a manned vehicle, in view of the effluent problem.
4. Although the trapped radiation environment is "intolerable" by flight safety considerations, remote measurements of perturbing effects can be made.

Although auroral processes could be considered as one aspect of energetic particle dynamics in the magnetosphere, this area has been identified separately because auroral physics has long been recognized as a separate study area and, as such, has special problems and associated objectives.

The experimental techniques applicable to area 2 can be divided into three general classifications:

A. Chemical releases.

B. Energetic particle injection.

C. Electromagnetic wave irradiation.

Each of these categories includes many possible investigations. For example, electromagnetic wave irradiation (Category C) inclues wave-particle interactions, VLF irradiation to create particle instabilities, RF heating and resonance studies, and others. This structure, then, defines generic areas of experimentation and has the advantage of being general enough to include a broad range of perturbing experiments. On the other hand, it does not reflect scientific objectives on a one-to-one basis; thus, the individual critical issues in plasma physics are often related to experiments in several categories of objectives.

The concept of performing perturbing experiments is considered of great importance in investigating the space plasma. Its importance is related to one way in which laboratory plasma physics is performed, i.e., plasma properties and structure can be determined in the laboratory by varying a critical parameter (temperature or density, for example) until an instability develops. To understand the space environment, a similar program will be followed in which, for example, particle density or energy density could be varied until an effect is observed. Passive measurements of the environment are much less conclusive and have led to a number of theories to explain the observed phenomena. Active experiments should directly determine which of these theories are applicable.

In summary, in the subdiscipline of plasma physics, the following four research clusters were formed from the 82 critical issues judged to be suitable for a manned earth-orbital research program. A brief description of the research cluster is presented at the end of this subsection. More detailed descriptions are given in Appendix C.

Cluster No.	Title
4-PP-1	Spacecraft-Environment Interaction
4-PP-2	Energetic Particle Dynamics in the Magnetosphere
4-PP-3	Thermal Plasma in the Ionosphere and Magnetosphere
4-PP-4	Auroral Processes

SUBDISCIPLINE SYNOPSIS

4-P/C

Physics and Chemistry Laboratory

1. Research Objectives

Research objectives of the general program defined for the Physics and Chemistry Laboratory are aimed at exploitation of the unique characteristics of the space environment for conducting experiments not feasible on earth. Specifically, the characteristic of a long-term reduced gravity environment will be used to attain the objectives of (1) a basic undertaking of chemical reactions and various fluid phenomena in reduced gravity; (2) the direct use of low gravity in the production of unique materials in space; (3) collection of fluid behavioral data useful for the engineering of advanced generation space propulsion and life support systems.

2. Background and Current Status

Almost all of the research clusters studied for inclusion in the Physics and Chemistry Laboratory have had some previous experimental and analytical work performed in connection with earth-based laboratory, low-g drop tower, and aircraft tests. Some limited theories, supported by the limited drop-tower data available, have been developed for boiling heat transfer, liquid-vapor interface instability, and capillary flow in wicks. Some of the manufacturing techniques such as controlled density casting, levitation melting, crystal growth, and the production of thin films and foils are presently practiced on earth; however, the materials and sample sizes which can be formed in this way are limited by the existence of the one-g gravitational environment.

In all cases long-term low-g data is nonexistent; its generation is needed to confirm or develop new theories, engineering analyses, and material processing techniques. Supplemental information concerning the research clusters itemized in paragraph 1 will be obtained during planned programs such as Skylab A (flammability, composite casting, single crystal growth), and Apollo 14 flight (composites, immiscible liquids). Information generated during these programs, although helpful in studying research clusters in the Physics and Chemistry Laboratory, will be incomplete for the stated research objectives. Performance of the experiments delineated for the Physics and Chemistry Laboratory is necessary for the completion of the research objectives.

3. Description of Research

The experimental approach necessary for the collection of low-g data involves, for the most part, standard laboratory procedures and data recording equipment. The required experiments can be performed in one central facility thereby enabling diagnostic equipment and test chambers to be shared by several research clusters.

The participating astronauts must be familiar with the experiment objectives and must be able to adjust experiment variables depending upon the progress of the experiment or the outcome of an individual run. This could also be accomplished through direction from a ground-based scientist, although realtime decisions by the participating astronaut will be more efficient and, in some cases, absolutely necessary if useful data is to be generated.

4. Impact on Space Vehicle

Astronauts will be required to activate experimental equipment, record measurements and readjust or install different test samples. Data recording is necessary aboard the space vehicle. However, because time does not deteriorate the value of the data, it may be stored in film or tape form aboard the station and physically carried back to earth with a resupply vehicle (if this is more efficient than data telemetry). In some research clusters return of material samples to ground stations is desirable in order that extensive material testing equipment not be required in space. Due to the presence of extreme temperature and power requirements in some of the research clusters, heat dissipation and crew safety considerations can have an impact on the space vehicle.

Space vehicle power required will range from average values of 0.2 to 5.0 kilowatts and peak values up to 20 kilowatts for short periods of time depending upon the research cluster. Exact values of the total electrical energy required from the station will become apparent after the deriving of a more detailed description of the individual experiments.

A variety of fluids and materials are to be used during the course of the experiments including cryogens and reactive substances. These must be resupplied at a rate depending upon their consumption or the ability for bringing them to the space vehicle from earth.

Astronaut participation in experiment execution ranges from 6 to 144 man hours, depending on the research cluster, with a total of 425 man hours envisioned at this time for the total laboratory.

The volume required for the basic laboratory facility is estimated at approximately 400 cubic feet with an additional storage volume of approximately 380 cubic feet for expendable fluids and solid test samples. Weight of the basic facility (equipment and apparatus common to most of the research clusters) is approximately 600 lb with an additional weight requirement of approximately 7,440 lb for expendables and specialized equipment.

5. Required Supporting Technology Development

In addition to the design and development of the basic experiment facility, supporting research and technology is required for the processing and data collection equipment. Power supplies, fluid transfer pumps, flowmeters and other standard laboratory equipment must be modified and optimized (lightweight, greater efficiency and smaller dimensions) for use aboard the Physics and Chemistry Laboratory. Development will also be required of special apparatus for the chemical reaction, zone refining, crystal growing, and thin film and foil experiments. Of prime importance is the knowledge and control of the gravity level. This will require sensitive three axis accelerometers (down to 10^{-6}g) and low-g isolation mounts (or an unmanned subsatellite) for limiting acceleration levels during the course of individual experiments. The development of necessary space vehicle heat transfer equipment may involve the use of heat pipes for the transport and concentration of thermal energy.

SUBDISCIPLINE SYNOPSIS
4-CR
Cosmic Ray Laboratory

1. Research Objectives

The primary objective of the Cosmic Ray Physics Laboratory is to ascertain the content, sources, energy spectra, acceleration mechanisms, and lifetimes of the galactic and extra-galactic cosmic radiation. This includes the study of gamma ray astronomy and the search for rare or unusual particles such as antinuclei, quarks, magnetic monopoles, and transuranic elements. A secondary objective is the utilization of this natural radiation as a source or particle beam for studying high-energy interaction physics.

2. Background and Current Status

Measurements of the incident cosmic radiation have been made on the earth's surface and from balloons or spacecraft. Ground-based measurements of the air showers the particles produce provide a technique for analysis of the energy spectrum and angular distribution of primaries incident on the atmosphere above 10^{14} eV. On the low-energy side, terrestrial and solar magnetic fields place a practical limit of 10^6 to 10^7 eV per nucleon for energy analysis of the radiation through the use of balloons and satellites. The region between 10^{10} and 10^{14} eV contains very few quantitative measurements and thus forms an important area for study from a manned space platform.

Experimental searches for cosmic gamma rays began in 1959. Outside the galactic plane measurements of diffuse sources exist only for energies up to 6×10^3 eV;

above this energy only upper limits exist for the flux except for an integral measurement at 10^5 eV. Diffuse high-energy gamma rays have also been measured in the galactic plane; the strongest sources are at the galactic center. With the experimental resolution of $\pm 15^{\circ}$ it was not possible to distinguish between a number of discrete sources and a line source along the galactic disc. To date, there exist no clear examples of discrete gamma ray sources.

Experiments to detect the rare and unusual particles in the cosmic rays have, for the most part, led only to the placing of upper limits on their fluxes. One possible exception to this is the case of the transuranic elements. Experiments involving track counting techniques have been used on balloons, resulting in the possible observation of three particles with charge greater than 96; there are, however, experimental uncertainties in the results. Needed in all of the experiments in this group are additional measurements-such as would be possible on a space vehicle with large area detectors and long counting times. In the utilization of the cosmic ray beam for high energy particle experiments, testing some models of nuclear interactions, such as the Regge pole model, requires higher energies than those available at accelerators. There are several predictions that require energies only a few orders of magnitude greater than that available at present as, for example, the equality at high energies of particle and anti-particle cross sections.

Some data on spallation cross sections are available from balloon-borne nuclear emulsion experiments, but more extensive studies are required.

3. Description of Research

All of the research clusters must be considered as a whole in order to make the most efficient use of a cosmic ray laboratory. Because the flux of primary cosmic rays decreases rapidly with increasing energy and increasing charge, all of the high-energy cosmic-ray research clusters require a large geometrical factor, or solid angle-area product. Thus, the facility should be designed to be as omnidirectional as possible. Entrance apertures should be on the order of several square meters for each experiment. Particles arriving from all directions in space, except those moving from the direction of the earth, would be acceptable for most of the research clusters.

The experimental setup for the measurement of the properties of cosmic ray primaries will consist, in general, of a charge identification module, a spectrometer, and a total energy counter. The spectrometer must be used to determine the sign of the charge in the antinuclei and electron-positron experiments. It also provides momentum and charge information for all of the experiments. Time of flight analysis must also be used to determine the sense of the particle direction through the system for the antiparticle experiments. Gamma ray measurement techniques, otherwise identical with electron-positron techniques, require the addition, at the entrance of the system, of a high-Z converter (e.g., lead) for converting the gamma rays to electron-positron pairs.

The interaction experiments will require the instrumentation described above, with the addition of a liquid or solid hydrogen or deuterium target. A magnetic spectrometer will be used to analyze the reaction products and to study, for example, the transverse momenta distributions from the high energy interaction. Required in order to complete the system are a total energy detector, scintillators - both in coincidence and anticoincidence - and time-of-flight analysis, for determining energies, reducing background, and roughly defining particle trajectories.

The initial setup and checkout of each experiment would be performed by a technician and physicist. They would be aided by an onboard computer for automatic setting and testing of the logic sequence and signal trigger levels.

The experiment data from the various counters would be digitized and placed in computer storage for later transmission. Once any experiment had been set up, aligned, and calibrated, it should be run continuously. There should also be automatic periodic testing and calibration until sufficient data has been collected to provide for statistical analysis.

4. Impact on Space Vehicle

The support requirements for the cosmic ray laboratory are summarized by the table below, in which it has been assumed that the superconducting magnet and the target will be passively supplied with cryogens. If an active system were used, an additional 7 KW of power would be required. It should also be noted that the TANC* is of segmented construction, thus allowing this rather massive detector to be assembled in place; the individual segments are supplied over an extended time period. This is possible because many experiments could begin before the TANC is either available or completely assembled. A total laboratory weight (excluding the structure or module), is estimated at 35,000 pounds and requires 2 KW of power.

Instrument	Ave. Power	Weight (lb)
Magnet	--	5,000
TASC**	50 W	3,000
TANC*	150 W	20,000
TARGET	--	1,500
ANCILLARY EQUIPT.	350 W	1,500
COMPUTER	200 W	700

Two problems created by the field of the superconducting magnet are (1) torques on the station due to interaction with the earth's magnetic field and (2) possible magnetic interference with other onboard equipment. Use of a pair of superconducting magnets will minimize these problems and makes it possible to set up two independent experiments. The disadvantages of this approach are increased system weight and cryogen supply requirements. These increases are not included in the summary table above.

For most of the experiments, the trapped particle background should be ept to a minimum, which requires an orbit well outside the radiation belts and standby mode operation during passage through the South Atlantic anomaly.

Pointing requirements for the gamma ray experiment are stability of 0.1° or better for the point source mode and slow scanning both on and off the galactic disc for the diffuse source mode.

5. Required Supporting Research and Technology

Large superconducting magnets for space application are presently under devel-

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* Total absorption <u>nuclear</u> cascade counter
** Total absorption <u>shower</u> cascade counter

opment. Further work in this area, including a suitable cryogenic system and, if possible, improved superconducting materials, are required for the cosmic ray laboratory.

Total absorption shower cascade (TASC) counters have been designed and built, but total absorption nuclear cascade (TANC) counters are still in the design stage. Both are needed for the laboratory.

The development of higher spatial resolution counters would be useful for all experiments, but nuclear emulsion and spark chambers, in combination, may prove adequate. Liquid xenon proportional chambers are presently under development; this may provide improved resolution.

Other possibly useful instruments presently under design or development are the transition radiation detector (which would give a direct measure of the total energy of a particle) and the streamer chamber (to make particle track measurements). This latter instrument would have the advantage of being post-event triggerable (a property not enjoyed by the bubble chamber).

SUBDISCIPLINE SYNOPSIS

4-PP

Plasma Physics

1. Research Objectives

The fundamental objective of the Plasma Physics Subdiscipline is to gain a more complete understanding of the basic physical processes which underlie the observed characteristics of the ionosphere and near regions of the magnetosphere. Implicit in this objective are the areas of solar-terrestrial relationships, geomagnetism, upper atmosphere physics, ionospheric physics, and the radiation belts. Although each of these areas can sometimes be represented as independent research disciplines, they contain sufficient commonality and interdependence in experimental approaches so that their classification into the single research area of Plasma Physics is valid. Moreover, the complexity of the phenomena suggests the need for a comprehensive and coordinated program of research. Therefore, identification has been made of four research clusters, which--although interdependent to a large degree--provide a useful framework for the development of a Plasma Physics research program and its associated laboratory.

2. Background and Current Status

From time immemorial, man has observed the varied manifestations of ionospheric and magnetospheric phenomena in the aurora. In more recent years his observation platform has been extended above the ground by spacecraft and rockets. As a result of these observations, various theoretical explanations for the observed phenomena have been derived; however, more complete observations tend to demonstrate the inadequacy of particular theories implying the need for more information. The greatest limitation of ionospheric and magnetospheric research stems from the fact that the past experimental programs have been limited to passive measurements. Thus, there has been no controlled variation in the experimental parameters such as is normal in laboratory experiments. Only natural environment changes, such as those associated with geomagnetic storms, solar flares, solar eclipses, and auroral displays, have been studied. The integrated approach possible with a manned platform will

C-4

increase the value of doing active experiments in which the environment will be modified in a known and controlled manner. Specific experiments to test the applicability of specific theoretical treatments will be possible.

3. Description of Research

The breakdown in terms of the experiment techniques for the plasma physics laboratory cannot be structured as were the research objectives.. However, there are experiments which can be used in various modified forms to answer questions in more than one of the research clusters identified. Several such experiments constitute part of the suggested initial scientific program. The possible perturbation techniques include:

1. Energetic particle injection (electron, ion, plasma accelerators);
2. Chemical releases (solar excited elements and electro negative and and positive gases such as Ba and SF_6);
3. Electromagnetic irradiation (Radio frequency, VLF).

Five different experimental techniques have been described for the four clusters, with a great deal of cross correlation between them. For example, the three environmental investigation areas utilize VLF wave irradiation techniques, but for different purposes.

Listed below are experiments suggested for each of the research clusters. They are intended to be representative, not exhaustive.

4-PP-1 Spacecraft-Environment Interaction

The objective of this cluster is the determination of the spatial extent and properties of the disturbed plasma volume generated by the passage of a large body through the ambient neutral and plasma environment.

1. Study of the perturbed region surrounding the space station using boom-mounted instrumentation and maneuverable subsatellites.
2. Study of the perturbed region surrounding passive inert bodies of various geometrical configuration.
3. Monitoring of undisturbed environment from a subsatellite.

4-PP-2 Energetic Particles in the Magnetosphere

The initial objective of this cluster is the examination of the.

possible origin of the energetic particles, together with an understanding of the dynamic processes which result in their energization, trapping, and loss--

1. Injection of 40 kev electrons at high L values to stimulate precipitation processes and VLF emission;
2. Injection of tracer ions (Li^+ or Ba^+) at high L values to study particle diffusion and energization;
3. Mapping of geomagnetic field structure using energetic particle beams;
4. Injection of VLF to cause particle dumping from wave-particle interactions.

4-PP-3 Thermal Plasma in the Magnetosphere and Ionosphere

The objectives of this cluster are to understand the processes by which the ionospheric and magnetospheric thermal plasma is formed and the processes by which it is controlled and distributed throughout the exosphere--

1. Study of natural resonances;
2. Heating and modification of the ionosphere with RF waves;
3. Ducting of VLF waves;
4. Occurrence of beam-plasma instabilities.

4-PP-4 Auroral Processes

The objectives of this cluster are to identify possible low altitude processes important in auroral dynamics and to study in a quantitative manner the interaction of energetic particles with the atmosphere--

1. Modification of auroral characteristics by chemical releases at altitudes between 90 and 150 Km.;
2. Generation of artificial aurora by energetic particle beams;
3. VLF irradiation to cause particle dumping to initiate auroral behavior.

In each research cluster, several specific experiments have been developed and typical experiments are included. Modification of the described experiment for adaptation to other clusters are described in the synopses for those clusters. The required scientific equipment and support have been identified and integrated into a laboratory configuration.

In addition to the cross correlation of experimental techniques with research clusters noted above, there exists commonality in the use of equipment and facilities throughout the experiment program. Just as with other laboratories, different experiments can be performed by reconfiguring the equipment for achieving the particular set of techniques and measurements required for each experiment. In some cases, however, the difference between a tracer experiment and a perturbing experiment will result in major equipment differences.

4. Impact on Space Research Facility

The Plasma Physics Subdiscipline is unique among the various areas considered in this program. It is the only one in which modification of the natural environment is attempted. The type of experiments that can be performed depends strongly on the vehicle orbit. In addition, certain experiments must utilize correlated ground-based measurements; here again, orbital constraints will determine the availability of the ground stations.

Average power requirements will range from 100 to 500 watts, depending on the experiment, with peak powers of 20 kilowatts for short periods of time (or seconds). The peak power requirements apply only to the perturbing experiments. Power requirements for the passive and tracer experiments fall within the 1 kw range. Data rates of up to one megabit/second will also be required. The minimum crew requirement is for (1) a physicist who will determine experiment procedure, monitor measurements, direct activities, and analyze data, and (2) an electromechanical technician for deployment, set-up, calibration, and control of the apparatus.

In addition to the above parameters, the study of the spacecraft's undisturbed local environment and the wake produced in the environment depends strongly on the spacecraft design. Therefore, such parameters as the uniformity of the spacecraft surface, power transmissions, effluent releases, and surface protuberances require careful design so that their individual effects on the local environment can be determined. If these limitations overly restrict spacecraft design, initial wave studies could be conducted with inflatable bodies of controlled shape. After a theory for simple bodies has been verified, measurements on a non-ideal station would proceed.

Required Supporting Technology Development

The critical technology which is required for the planned experiments includes:

1. Maneuverable satellites and subsatellites;
2. Improvement in the efficiency of chemical releases;
3. Development of high power, space facility carried RF and VLF transmitters;
4. Development of high current, 10-200 kev ion and electron accelerators;
5. Development of techniques to maintain space research facility neutrality while accelerators operate.

3.6 SCREENING AND GROUPING OF CRITICAL ISSUES IN COMMUNICATIONS AND NAVIGATION

The organized overview analysis (Subsection 2.6) defined 315 critical issues in the discipline of Communications and Navigation. This overview is presented schematically in Charts 5-1 through 5-9 in Appendix A, and in the form of the end-product questions (critical issues) in Table 5 of Appendix B. It was recognized in this development that many of the questions raised could not be answered immediately by experimental investigations. For example, development of the communication needs of future networks is a subject for detailed engineering study and analysis during the initial phases of program development. Such questions do not lead directly to experimentation, but must be considered in a discussion of the systems necessary to fulfill requirements before the critical issues in Communications and Navigation can be described in detail. For some of the more advanced systems, it is impossible to delineate technology and experimentation requirements until such studies have been performed. The product of these studies will define the experimentation requirements.

It should be observed that the actual delineation or enumeration of critical issues is somewhat artificial in an overview of a field of this magnitude. Particularly when components are listed, they may be duplicated for each of the systems considered. Thus, what appears to be a single critical issue may actually be repeated many times. An example is found in transmitters.

for communications systems, which may be identified as a single technology critical issue, but actually they may take many forms in the various systems involved. Several different transmitters may be required, even in a single frequency band, where the bandwidth, power requirements, or multiple service requirements differ among the various systems.

The criticality of such technology items also varies with the system requirements. Thus, a transmitter for a narrowband communication system may not be considered a critical item because it is an off-the-shelf item. In certain applications and in selected frequency bands, however, transmitters or receivers may become critical items. An example of the latter is the receiver requirement for wideband laser communications. At present, no tunable CW laser is available for space communications systems.

Investigations in this area are being pursued under various NASA and military programs, but they cannot lead to space experimentation until the development work has proceeded further. Such development must be identified in terms of space applications, if the full potential of laser communication systems is to be achieved. Thus, a critical issue in tunable laser communications receivers may first imply a long-term ground-based research and development program. After development of such a device, it would be necessary to demonstrate the capability of the resulting system and the successful performance of the hardware in space. Consequently, an overview of experimental system projects might include the demonstration in space of a tunable laser receiver, although at this writing, it is too early to identify the nature of the device to be tested. This leads to a category of space testing of components whose development is somewhat speculative, which cannot be identified precisely, and whose date of availability cannot be accurately forecast. Thus, a critical issue emerges, indicating a need for space testing of future systems. Through the mechanism of the overview, what has been identified is a continuing need for space testing and demonstration at the subsystem and system levels. This is a continuing need and it implies a requirement for prolonged space research.

It is seen, therefore, that the enumeration of critical issues is somewhat ambiguous of duplications of items under the categories of systems and technology and because many critical issues become critical for different systems. What may be listed as a single critical issue may be a critical issue for each system that is to be developed. Determination of the criticality of certain system issues requires preliminary system design study. In many cases, the overview development corresponded to the steps of program development and, as such, is included in the overview for completeness, although it was acknowledged that these inclusions do not lead to experimentation until necessary analyses have been performed.

The analysis of the critical issues, in an attempt to identify space experimentation needs, was divided into three steps:

1. Screening for space research applicability.
2. Screening for manned space research applicability.
3. Examination of ongoing programs to avoid duplication of effort.

The screening for space research applicability eliminates critical issues that can be satisfied entirely by non-space-based research. The intent of the screening for manned space applicability is to eliminate the critical issues that can be satisfied by experiments using automated satellites. The examination of ongoing programs is intended to eliminate critical issues that will be satisfied by experiments carried out under programs already authorized. As discussed later in Subsection 3.6.4, the rigid application of this screening process appeared to eliminate all but nine critical issues, primarily because man is <u>not required</u> for experimentation unless he is already a part of the system under test.

Five of the nine are concerned with evaluation of man's capability in space to erect antenna structures, to calibrate and repair them, and to perform inspections. Several deal with autonomous space navigation techniques employing man in the control loop. Space qualification of components and developmental testing was one of the critical issues where man was judged essential. In all cases man was an integral part of the experimentation process.

Considering the cumulative effect of manned participation in many research activities, man's presence was judged to be helpful in 88 of the 90 critical issues that survived step 2, above. Some of these critical issues represent ongoing needs for broad space investigations and cannot be identified on a one-to-one basis with "point" or single purpose satellite experiments. Eighty-eight is a large number of point experiments when it is considered that at least one launch is needed to complete each investigative program.

In the course of this screening process, an interesting dichotomy was revealed. The first position is that activities in which man is essential are very limited. Moreover, if man is helpful but not essential to experiments, a detailed justification for man's participation is difficult. Also, the five essential classifications that deal with man being an integral part of the experimentation process have been included to some degree in the Apollo and Skylab activities and therefore might be eliminated under Step 3. On the other hand, the number of critical issues to which man would be helpful, although not essential, is too large to be ignored in a program of this type.

Performance of a large number of experiments having common measurement objectives is more suited to a laboratory or test facility where general-purpose equipment may be configured into a large number of experimental setups. This view is divergent from the presently established philosophy of configuring individual (dedicated) automated satellites to point experiment measurements.

Another interesting phenomenon was observed. The critical issues that require man's participation are basically centered around the fundamental question of what man in space can contribute to technology, rather than to the fundamental question presented in the overview of providing services to communication and navigation users. Since such services have already been provided, and will continue to be provided on a large scale by automated satellites, the critical issues in which manned experimentation is essential are primarily concerned with the evaluation of what man can contribute rather than to the provision of communication services. Certainly, the presence of man in space is necessary for such evaluation. These critical issues more properly combine with research under the discipline of Manned Space Flight Capability instead of being restricted to the Communications and Navigation discipline.

In view of the dichotomy discussed above, it is constructive to develop the experiments around the 88 critical issues in which man may be helpful, by adopting the philosophy that a general-purpose test laboratory having broad capabilities is the most desirable configuration. It is suggested that this approach be examined by further analysis for its cost effectiveness. The laboratory approach to testing will satisfy a large number of information requirements.

By inspecting the large number of critical issues remaining, it was convenient to combine critical issues into common measurement activities for writeup in the format of Research Cluster Descriptions. This combination or clustering of critical issues has the merit of defining the goal or objective of a group of investigations consisting of several point experiments. Since the broad research descriptions also require definition of experimental hardware for the investigation, the formal pursuit of this approach would necessitate the preparation of a large number of hardware descriptions under each research cluster in order to complete the effort. The selected grouping finally derived consists of 14 research topics augmented by two general research activity support groups. Each of these 16 research clusters has been described in sufficient detail to elucidate its instrumentation requirements and space facility support requirements. These research cluster descriptions are presented in Appendix C.

The following subsections describe the screening process that has been briefly outlined above.

3.6.1 Screening for Space Research Applicability

The space research screening consisted of two sequential steps. The first was an initial screening operation, which was designed to eliminate critical

Table 3-32

PRELIMINARY COMMUNICATIONS SCREENING

FOLDOUT FRAME 1

Program Area	Intermediate Area	Specific Categories	Total	Covered by Other Disciplines (Critical Issues)	No.	Requires Engineering Analysis, Design Study, or Data Evaluation	No.	Requires Primarily Theoretical Analysis	No.	Requires Resolution of Political and Jurisdictional Responsibility	No.	Candidate for Space Experimentation	No.
5.1.1 Applications	5.1.1.1 Space Mission Support		15			Manned spaceflight (7) Near-Earth experiments, lunar missions, planetary	12					Mission data relay	3
	5.1.1.2 Broadcast		5							TV distribution	1	Special interest TV, educational TV, teleclub systems, direct TV to homes	4
	5.1.1.3 Information Networking		5							Educational TV Connect remote computers	2	Connect libraries, Connect underdeveloped areas to major centers, High-resolution images	3
	5.1.1.4 Data Collection		6			Random access techniques Modulation techniques Low-cost user equipment Ground data processing	4					Store and forward memories Location techniques	2
	5.1.1.5 Service Requirements		4			Services Modulation techniques Constraints Technology	4						
5.1.2 Research and Development	5.1.2.1 Theory	User requirements Signal design analysis Signal environment model Performance analysis Propagation model Information processing	8 5 1 1 1 3			User requirements	8	Signal design analysis (All) Signal environment model Performance analysis Propagation model Signal averaging Redundancy reduction coding	5 1 1 1 3				
	5.1.2.2 Environment	Terrestrial noise Source identification X-ray and particles Cosmic noise Spacecraft operating environment	4 9 4 4 6	Event counters, ionization, plasma, shields Frequency, spatial, temporal, polarization dependence	4 4	Transmitter signatures, spurious radiation, data processing NASA-related objectives	3 1			Military objectives Security objectives Intelligence objectives	3	Frequency, geographic, temporal dependence, Amplitude statistics Information monitoring, RDF techniques Pressure, charge density, temperature, material properties, RFI, Meteoritic bombardment	4 2 6
	5.1.2.3 Propagation	Ionospheric effects Tropospheric effects Plasma effects Noise and RFI models Multipath	8 8 6 8 7			Geographic distribution Probability of operation Radiated energy vs Frequency Angular distribution Propagation modes Interference performance, iteration	7					Attenuation, refraction, polarization rotation, signal mixing variance, time spreading, frequency spreading, reflection Clear air attenuation, cloud attenuation, rain attenuation, refraction, time spreading, frequency spreading, variance, reflection Plasma effects (All) Compare OHS with model Multipath (All)	8 8 6 1 7
	5.1.2.4 Technology	User requirements Spacecraft antenna Low-noise receivers Transmitters Spacecraft memories Signal processors Passive RF components Primary power New devices Low-cost, small user terminals Input-output devices Other spacecraft systems EVA support technology EVA contribution to technology development Astronaut safety Demonstration and test	12 6 6 7 8 6 6 6 1 8 5 7 7 5 4 3			User requirements (All) Wide-bandwidth antennas frequency Low-noise receivers Transmitters Spacecraft memories Signal processors Passive RF components Primary power New devices Low-cost ground terminals Input-output devices Other spacecraft systems EVA support technology Astronaut safety	12 2 6 7 8 6 6 6 1 8 5 7 7 4					Large-aperture antenna, Multiple-beam antenna, Interferometer structure, Phased-array antenna Antenna Deployment Test and calibrate antenna Repair and replacement inspection Observe flexible structures System simulation Subsystem test Orbital flight qualification	4 5 3
5.1.3 Resource Management	5.1.3.1 Frequency Allocation		8							Frequency Allocation (All)	8		
	5.1.3.2 MM Wave Demonstration		4							Commercial	1	Space-to-space Space-to-ground, high data rate	3
	5.1.3.3 Optical Frequency		4									Space-to-space Space-to-ground, position determination, high data rate	4
	5.1.3.4 Future Needs		5							Future Needs (All)	5		
	5.1.3.5 Usage and Control		5							Usage and control	5		
Total			241		8		124		11		25		73

5.1 Communications

FOLDOUT FRAME 2

Table 3-33

PRELIMINARY NAVIGATION AND TRAFFIC CONTROL SCREENING

5.2 Navigation and Traffic Control

Application Area	Intermediate Area	Specific Categories	Total	Critical Issues: Covered by Other Disciplines	No.	Requires Engineering Analysis, Design Study, or Data Evaluation	No.	Requires Primarily Theoretical Analysis	No.	Requires Resolution of Political and Jurisdicational Responsibility	No.	Candidate or Space Experimentation	No.
5.2.1 Space Needs	5.2.1.1 Earth-Oriented Systems		5			Data relay satellites	1	Range and range rate links Ground data processing system	2			Laser ranging	2
	5.2.1.2 Autonomous Naviation Systems		9			Autonomous navigation system	6					Planetary position observation Star occultations by planets Mode handover	3
5.2.2 Aircraft and Marine Needs	5.2.2.1 Navigation	Passive system techniques Active system techniques	12 12			Ground station support User equipment Communication link to transmit data to user	17					Active and passive system techniques	7
	5.2.2.2 Surveillance	Position-fixing techniques Air traffic control functions	2 4	Traffic control communication net	1	Air traffic control displays data processing center Active satellite navigation system	3					Range transmitted from user to control center Position reporting from user via satellite	2
	5.2.2.3 Collision Avoidance	Alarm communications Data Processing Beacon transmissions	1 1 1			Data Processing	1			Alarm communications	1	Beacon transmissions by all craft	1
	5.2.2.4 Enroute Communications	Position reporting Special services: Weather reports Company communications Passenger services Solar flare warnings Air traffic control circuits	2 2 1 2 1 1	Position reporting Weather reports	2 2	Solar flare warnings	1			Company communications Passenger services Air traffic control circuits	1 2 1		
	5.2.2.5 Search and Rescue	Vehicle location techniques Rescue operation control	3 1			Vehicle location techniques	2					Satellite angle determination Rescue operation	1 1
5.2.3 Space Vehicle Launch and Reentry Needs	5.2.3.1 Aerospace Clearances	Near-term requirements Future requirements	1 1			Near-term requirements Future requirements	1 1						
	5.2.3.2 Local Traffic Control	System requirements Available system concepts Near-term: VHF nets Future: satellite communication nets	2 2 1 1	Radar information navigation system Future satellite communication nets Near-term: VHF nets	2 1 1	System requirements	2						
	5.2.3.3 Corridor Safety		6	HF and VHF guard channels	1	Local VHF nets Navy fleet broadcast Future company communication	3			Merchant shipping Foreign shipping	2		
Total			74		10		38		2		7		17

TABLE 3-34

EXAMPLES OF TREATMENT OF CRITICAL ISSUES IN COMMUNICATIONS AND NAVIGATION

Category	Example	Remarks
1. Covered by other disciplines	5.1.2.2.3 X-rays and Particles 5.1.2.2.3.1 Event Counters How does the number of discrete events per unit area, per unit solid angle, and per second vary with spacecraft orbital altitude?	A space physics experiment
2. Requires engineering analysis, design study, or data evaluation	5.1.1.1 Space Mission Support 5.1.1.1.4 Planetary Missions What are the communication requirements for support of automated spacecraft for planetary missions?	Assumes ongoing program mission definition and engineering analysis for each mission
3. Requires primarily theoretical analysis	5.1.2.1.2 Signal Design Technique Analysis How many various signal design techniques contribute to satisfaction of user requirements?	A series of problems in modulation theory requiring further ground-based testing prior to space research
4. Requires resolution of political and jurisdictional responsibilities	5.1.1.3.3 Distribution of Educational TV Programming	Both AT&T and COMSAT CORP have evidenced interest in applications of satellite links to provide this service. The economic advantages of this application may be such that R&D should be supported by the user rather than by NASA
5. Potential for space experimentation	5.1.2.4.16 Testing Subsystem in Orbit Do components and subsystems actually perform in orbit after passing ground simulation acceptance tests?	A broad category of space demonstration, including various items of hardware within Research Objective 5.1.2.4

intelligence. Subsystems may be developed by NASA for its manned space flight programs and operated by military personnel who are a part of the NASA programs. The fifth category, those critical issues having potential for space experimentation, is the category of surviving critical issues that pass on to the other screening considerations. The following paragraphs summarize the screening results, reference Tables 3-32 and 3-33.

Eight critical issues, all in the intermediate area of "research and development environment," were eliminated because they are covered by the Space Physics discipline.

It was judged that 124 critical issues in Communications and 38 in Navigation will become tractable for experiment definition only after several years of engineering analysis, design study, and evaluation of terrestrial laboratory work (Tables 3-32 and 3-33). These issues were therefore eliminated from further consideration in the present study. A case in point is the lack in the open literature of accurate forecasts of further user requirements. This type of information is important because it leads to the definition of space repeater circuits, which in turn, permits the sizing of operational networks. The projection of future traffic loads, no matter how poorly defined, inevitably influences a multitude of critical technology decisions on such matters as types of modulation, multiplexing, and standards of quality for each system application being postulated.

In this study, the Communications and Navigation discipline is primarily oriented to space so as to delineate the field and make it more tractable. For this reason, it is reasonable that testing or operation in space will be essential at some time for the development of the systems in question. Critical issues in which the question arises as to whether a space system is the best means of providing certain services can usually be resolved by comparative studies of competing systems rather than by experiments. This was the primary reason for the category, "Requires Engineering Analysis, Design Study, or Evaluation."

Eleven critical issues in Communications and two in Navigation (Tables 3-32 and 3-33) were eliminated because the questions largely involve theoretical matters. There is some duplication between this category and the preceding one, the difference between them being whether it is engineering analysis and data evaluation or whether the question deals largely with theoretics.

Twenty-five critical issues in Communications and seven in Navigation were eliminated because coordination is required with other agencies and because political questions need resolution prior to pursuit by NASA.

Seventy-three of the original 241 critical issues in Communications and 17 of the original 74 critical issues in Navigation and Traffic Control remained as potential candidates for space experimentation. These 90 critical issues received screening treatment based on the three steps described in the introduction to this Subsection (3.6).

The space criteria employed in selecting critical issues for research in the Communications and Navigation discipline were the following:

1. Orbital characteristics
   A. Orbital altitudes-usually required for geometry simulation.
   B. Wide-area geographic coverage-required if a satellite station must communicate with many other terminals.
   C. Target selection-interpreted here as applying if communication with one terminal is required.
   D. Repeatable ground track-may be advantageous or disadvantageous.
   E. Orbital velocity/altitude (V/H) ratio-angular tracking velocity at either end of the link.
   F. Relative velocity-leads to Doppler shifts.
2. Space environment characteristics
   A. Gravitational effects-zero or artificial gravity.
   B. Atmosphere (vacuum)-usually an essential requirement for space qualification.
   C. Meteoroids-may be disadvantageous but may also be unavoidable.
   D. Atmospheric attenuation-a part of the environment; more data are needed.

E. Cosmic radiation-a part of the environment; more data are needed.

F. Radiation belts-a part of the environment; more data are needed.

The 73 critical issues in Communications and the 17 in Navigation were rated against these space selection criteria. The procedure was similar to the overall procedure described in Subsection 3.1. It is displayed in the first 12 columns of Table 3-35. For each critical issue, it was judged that at least one aspect of the orbit or space environment was essential, and these 90 critical issues were all retained as indicated by the checks (√'s) in column 13. This finding tends to confirm the expectation that testing or operation in space will be essential at some time during the development of Communications and Navigation systems in space.

3.6.2 Screening for Manned Space Research Applicability

Many considerations are brought to bear when manned participation in space experiments is evaluated in terms of the expected experimenter contribution in comparison with any mission degradation that may result from man's presence.

Some measurements suggested by the critical issues satisfying the space criteria may require extended periods of experimenter activity to obtain significant data. An example is found in mapping the terrestrial noise received at earth-illuminating space antennas. The contributions to such noise include natural and man-made noise, and the latter varies with time of day as well as with geographic location, being a maximum over heavily populated areas. A complete map of the earth's surface will require large statistical sampling and may involve more than one type of satellite, some of which may be automated. If it is desired to extend the terrestrial noise maps to the polar regions, the use of automated polar satellites is probably the most advantageous method. When this experiment or objective is combined with that of noise source identification, the magnitude and nature of the measurement program becomes more apparent. One or both of these experiments will require the identification and cataloging of noise sources and the distribution of analyzed data to principal investigators for analysis. Since the

FOLDOUT FRAME

Definition of Symbols

E = Essential
H = Helpful
N = No Effect
T = Tolerable
I = Intolerable
U = Effects Unknown

Space Research Selection Criteria: Orbital Characteristics (columns 1–6); Space Environment Characteristics (columns 7–12). Manned Space Research Selection Criteria: Participation of Man — Scientist/Observer (14–17), Development Engineer (18–21), Technician (22–23); Flight Safety (24–27); Mission Performance Degradation (28–30). Relationship to Ongoing Programs (32–35).

Area	Topic	Critical Issue	Orbital Altitude	Wide-Area Geographic Coverage	Target Selection	Repeatable Ground Track	Orbital Velocity/Altitude (V/H) Ratio	Relative Velocity	Gravitational Effects	Atmosphere (Vacuum)	Meteoroids	Atmospheric Attenuation	Cosmic Radiation	Radiation Belts	Research Is Suitable for Space (√)	Real-Time Data Analysis and Evaluation	Multiple Sensor Use	Sensor Mode and Parameter Selection	Cooperation with Principal Investigator On the Ground	Target Selection	Sensor Operation and Parameter Variation	Evaluation of Sensor Design and Performance	Component Qualification Testing	Equipment Setup, Checkout Maintenance Calibration	Servicing of Sensors and Equipment Consumables	External Environment Extremes (Radiation, Temperature, Vacuum)	Exceeds Physiological Limits (Weightlessness, Fatigue Dehydration)	Excessive Psychological Stress (Sensor Deprivation, etc.)	Affects Crew Safety (High Voltage, Noise Level, Inflammables)	Accelerations Disturbances (Attitude Control, Crew Mobility)	Effluent Release Environmental Contamination	Repetitive Duty Cycles (Continuous High-Precision Observation)	Research is Suitable for Manned Space Research (√)	Program On Which Preliminary Information Has Been Developed	Program Completely Satisfying Research Requirements	Research Requirements Not Satisfied By Ongoing Programs (√)	Research Is Candidate for Future Manned Space Research (√√)
5.1 Communications; 5.1.1 Applications; 5.1.1.1 Space Mission Support	5.1.1.1 Manned Space Flight	.5 Mission Data Relay Satellites; .1 Planetary (or Lunar) Relay	E	N	E	E	T	U	H	H	U	N	T	U	√	H	N	H	H	H	H	H	N	H	N	N	N	N	N	T	T	N	√	Apollo/TDTR		√	√√
		.2 Earth Orbiting Relay	E	N	E	E	T	U	H	H	U	N	T	T	√	H	N	H	H	H	H	H	N	H	N	N	N	N	N	T	T	N	√	(TDRS, MINI-COM, FSSA DDRSS		√	√√
		3 Cross Space Relay	E	N	E	E	T	U	H	H	U	H	T	U	√	H	H	H	H	H	H	H	N	H	N	N	N	N	N	T	T	N	√	ATS-F-G 777, TDRS		√	√√
	5.1.1.2 Broadcast	1 Special Interest TV	E	N	N	E	N	I	H	U	U	N	T	U	√	N	N	N	N	N	N	N	H	H	N	T	I	T	T	N	N	N	√	ATS-F, -G		√	√√
		2 Educational TV	E	H	N	E	N	T	H	U	U	N	T	U	√	N	N	N	N	N	N	N	H	H	N	T	I	T	T	N	N	N	√	ATS-F, -G		√	√√
		3 Teleclub Systems	E	H	N	E	N	T	H	U	U	N	U	U	√	N	N	N	N	N	N	N	H	H	N	T	I	T	T	N	U	N	√	ATS-F, -G		√	√√
		.5 Direct TV to Homes	E	H	N	E	N	T	E	U	U	N	U	U	√	N	N	N	N	N	N	N	H	H	N	T	I	T	T	N	U	N	√	ATS-H, J		√	√√
	5.1.1.3 Information Networking	1 Connect Major Regional Libraries	E	H	H	E	T	I	N	N	N	N	T	I	√	N	N	N	N	N	N	N	N	N	N	T	I	T	N	N	N	N	√	ATS		√	√√
		2 Connect Underdeveloped Areas to Major Centers	E	H	H	E	T	T	N	H	N	N	T	I	√	N	N	N	N	N	N	N	N	N	N	T	I	T	N	N	N	N	√	ATS		√	√√
		4 High-Resolution Image Transmission	E	N	H	F	T	T	N	N	N	N	T	T	√	N	N	N	N	N	N	N	N	N	N	T	I	T	N	N	N	N	√	ATS, INTELSAT		√	√√
	5.1.1.4 Data Collection	1 Store and Forward Satellite Memories	E	E	H	F	N	T	N	N	I	N	U	N	√	N	N	N	N	N	N	N	N	H	N	T	I	T	N	N	N	N	√	Mars 1975 Viking 1973 ESSAT		√	√√
		4 User Location Techniques	E	E	E	E	U	T	H	H	U	N	T	N	√	N	H	N	N	N	H	N	N	H	N	T	T	T	N	T	U	T	√	ATS-F and -G (PLACE)		√	√√
5.1.2 Research and Development; 5.1.2.2 Environment of Communication System	5.1.2.2.1 Terrestrial Noise Measurements	.1 Noise Power Frequency Dependence	E	H	H	H	T	T	N	N	N	T	I	N	√	H	N	H	H	H	H	H	N	H	H	T	T	T	N	T	T	T	√	ATS, LES		√	√√
		2 Noise Power Geographic Coordinates	E	H	H	H	T	T	N	N	N	N	T	N	√	H	N	H	H	H	H	H	N	H	H	T	T	T	N	T	T	T	√	ATS, LES		√	√√
		3 Noise Power Temporal Dependence	E	H	H	H	T	T	N	N	N	N	I	N	√	H	N	H	H	H	H	H	N	H	H	T	T	T	N	T	T	T	√	ATS, LES		√	√√
		4 Short Term versus Average Noise Power	E	H	H	H	T	T	N	N	N	N	T	N	√	H	N	H	H	H	H	H	N	H	H	T	T	T	N	T	T	T	√	ATS, LES		√	√√
	5.1.2.2.2 Noise Source Identification	3 Information Monitoring	E	H	H	H	T	T	N	N	N	N	T	N	√	H	H	H	H	H	H	H	N	N	H	T	T	T	N	N	T	T	√	LES		√	√√
		.4 RDF Techniques	E	E	E	H	T	T	H	H	U	N	T	N	√	H	H	H	H	H	H	N	N	H	H	T	T	T	N	T	T	T	√	ATS		√	√√
	5.1.2.2.3 Spacecraft Operating Environment	1 Pressure Change versus Time	E	N	N	N	N	N	N	E	N	N	N	N	√	N	N	N	N	N	N	N	H	H	H	N	N	N	N	N	I	T	√			√	√√
		2 Charge Density	E	N	N	N	N	H	N	E	N	N	N	H	√	N	N	N	N	N	H	N	H	H	H	N	N	N	N	N	I	T	√			√	√√
		.3 Operating Temperature	E	N	N	N	N	N	E	F	N	N	N	U	√	N	N	N	N	N	H	N	H	H	H	N	N	N	N	N	N	T	√			√	√√
		4 Physical and Electrical Property Change	E	N	N	N	N	N	N	N	U	N	E	U	√	H	H	H	H	H	H	H	H	H	H	T	T	N	N	N	U	T	√			√	√√
		5 Spacecraft Systems EM Radiation	E	N	H	N	N	N	N	N	N	N	N	H	√	H	H	H	H	H	H	H	H	H	H	T	T	N	N	N	N	T	√			√	√√
		.6 Meteoritic Bombardment	E	N	N	N	N	N	N	E	E	N	N	N	√	H	H	H	H	H	H	H	H	H	H	T	T	T	T	N	N	T	√			√	√√
5.1.2.3 Propagation	5.1.2.3.1 Ionospheric Effects	1 Measure Ionospheric Attenuation	E	N	E	H	T	T	N	N	N	N	N	U	√	N	H	H	H	N	H	H	N	H	H	N	T	T	N	N	N	T	√	Alouette, Ariel, ESRO		√	√√
		.2 Measure Ionospheric Refraction	E	N	E	H	T	T	N	N	N	N	N	U	√	N	H	H	H	N	H	H	N	H	H	N	T	T	N	N	N	T	√	OV3, OV4		√	√√
		3 Measure Polarization Rotation	E	N	E	H	T	T	N	N	N	N	N	U	√	N	H	H	H	N	H	H	N	H	H	N	T	T	N	N	N	T	√	OV1		√	√√
		4 Measure Signal "Mixing"	E	H	E	H	T	I	N	N	U	N	N	U	√	N	H	H	H	N	H	H	N	H	H	N	T	T	N	N	N	T	√			√	√√
		5 Spatial and Time Dependence	E	H	E	E	T	I	N	N	U	N	N	U	√	N	H	H	H	N	H	H	N	H	H	N	T	T	N	N	N	T	√			√	√√
		.6 Measure Time Spreading	E	H	E	E	T	T	N	N	U	N	N	U	√	N	H	H	H	N	H	H	N	H	H	N	T	T	N	N	N	T	√			√	√√
		.7 Measure Frequency Spreading	E	H	E	E	T	T	N	N	U	N	N	U	√	N	H	H	H	N	H	H	N	H	H	N	T	T	N	N	N	T	√			√	√√
		.8 Measure Reflection Coefficients	E	H	E	E	T	T	N	N	U	N	N	U	√	N	H	H	H	N	H	H	N	H	H	N	T	T	N	N	N	T	√			√	√√
	5.1.2.3.2 Tropospheric Effects	.1 Clear Air Attenuation	E	H	E	H	T	T	N	N	N	E	N	N	√	N	H	H	H	H	H	H	N	H	H	N	T	T	N	N	N	T	√	OV, TACSAT LES, ATS		√	√√
		.2 Measure Attenuation by Clouds	E	H	E	H	T	T	N	N	N	E	N	N	√	N	H	H	H	H	H	H	N	H	H	N	T	T	N	N	N	T	√			√	√√
		3 Measure Rain Attenuation	E	H	E	H	T	T	N	N	N	E	N	N	√	N	H	H	H	H	H	H	N	H	H	N	T	T	N	N	N	T	√			√	√√
		4 Measure Troposphere Refraction	E	H	E	H	T	T	N	N	N	E	N	N	√	N	H	H	H	H	H	H	N	H	H	N	T	T	N	N	N	T	√			√	√√
		5 Measure Time Spreading	E	H	E	E	T	T	N	N	N	E	N	N	√	N	H	H	H	H	H	H	N	H	H	N	T	T	N	N	N	T	√			√	√√
		6 Measure Frequency Spreading	E	H	E	E	T	I	N	N	N	E	N	N	√	N	H	H	H	H	H	H	N	H	H	N	T	T	N	N	N	T	√			√	√√
		7 Spatial and Time Variance	E	H	E	E	T	T	N	N	N	E	N	N	√	N	H	H	H	H	H	H	N	H	H	N	T	T	N	N	N	T	√			√	√√
		8 Measure Reflection Coefficients	E	H	E	E	T	T	N	N	N	E	N	N	√	N	H	H	H	H	H	H	N	H	H	N	T	T	N	N	N	T	√			√	√√
	5.1.2.3.3 Plasma Effects	.1 Measure Signal Attenuation by Plasma	E	N	E	N	T	T	N	E	U	N	T	T	√	N	H	H	H	H	H	H	N	H	H	N	T	T	N	N	N	T	√	OV, ATS		√	√√
		.2 Measure Polarization Rotation	E	N	E	N	T	T	N	E	U	N	T	T	√	N	H	H	H	H	H	H	N	H	H	N	T	T	N	N	N	T	√			√	√√
		.3 Measure DC Breakdown Potentials	E	N	E	N	T	T	N	E	U	N	T	E	√	N	H	H	H	N	H	H	N	H	H	N	T	T	T	N	U	T	√			√	√√
		.4 Measure RF Breakdown Fields	E	N	E	N	T	T	N	E	U	N	T	E	√	N	H	H	H	N	H	H	N	H	H	N	T	T	T	N	U	T	√			√	√√
		.5 Spatial and Time Variance	E	N	E	N	T	T	N	E	U	N	T	E	√	N	H	H	H	H	H	H	H	H	H	N	T	T	N	N	N	T	√			√	√√
		6 Plasma Related Propagation Anomalies	E	N	E	N	T	T	N	E	U	N	T	E	√	H	H	H	H	H	H	H	H	H	H	N	T	T	N	N	N	T	√			√	√√
	5.1.2.3.4 Noise and RFI Models	7 Compare Noise Models with Observations	E	H	E	E	T	T	N	N	N	N	N	N	√	N	H	H	H	H	H	H	H	H	H	N	T	T	N	N	N	T	√	ATS, LES		√	√√
	5.1.2.3.5 Multipath	1 Measure Dependence on Terminal Altitude	E	E	E	E	T	T	N	N	N	N	N	T	√	N	N	N	H	N	H	N	N	H	H	N	T	T	N	T	N	T	√	TACSAT, LES, ATS 1-2-3		√	√√
		2 Measure Magnitude vs Terrain	E	E	E	E	T	T	N	N	N	N	N	T	√	N	N	N	H	N	H	N	N	H	H	N	T	T	N	T	N	T	√	TACSAT, LES, ATS 1-2-3		√	√√
		3 Magnitude vs Elevation Angle	E	E	E	E	T	T	N	N	N	N	N	T	√	N	N	N	H	N	H	N	N	H	H	N	T	T	N	T	N	T	√	TACSAT, LES, ATS 1-2-3		√	√√
		.4 Determine Frequency Dependence	E	E	E	E	T	T	N	N	N	N	N	T	√	N	N	N	H	N	H	N	N	H	H	N	T	T	N	T	N	T	√	TACSAT, LES, ATS 1-2-3		√	√√
		5 Measure Amplitude Statistics of Fading	E	E	E	E	T	T	N	N	N	N	N	T	√	N	N	N	H	N	H	N	N	H	H	N	T	T	N	T	N	T	√	TACSAT, LES, ATS 1-2-3		√	√√
		6 Measure Time Statistics	E	E	E	E	T	T	N	N	N	N	N	T	√	N	N	N	H	N	H	N	N	H	H	N	T	T	N	T	N	T	√	TACSAT, LES, ATS 1-2-3		√	√√
		7 Two Signal Fading Correlation	E	E	E	E	T	T	N	N	N	N	N	T	√	N	N	N	H	N	H	N	N	H	H	N	T	T	N	T	N	T	√	TACSAT, LES, ATS 1-2-3		√	√√
5.1.2.4 Technology	5.1.2.4.2 Spacecraft Antenna	1 Large Aperture Deployment	E	N	N	H	N	N	E	H	N	N	N	N	√	H	H	N	H	H	N	H	H	H	N	T	T	T	N	T	N	N	√	ATS-F		√	√√
		.2 Multiple Steerable Beams	E	E	E	H	N	H	H	H	N	N	N	N	√	N	N	N	H	N	N	N	H	H	N	T	T	T	N	T	N	N	√	777		√	√√
		4 Long Baseline Interferometers	E	H	E	H	U	H	E	H	N	N	N	N	√	N	N	N	H	N	N	H	H	H	H	T	T	T	N	T	N	N	√	ATS-F		√	√√
		.5 Phase Arrays	E	H	E	H	N	H	E	H	N	N	N	N	√	N	H	N	H	N	N	N	H	H	N	T	T	T	N	T	T	N	√	ATS-I		√	√√
	5.1.2.4.11 Manned Space Flight Contribution to Development	.1 Antenna Deployment	E	N	H	H	N	N	E	I	T	N	T	T	√	E	E	E	H	N	E	E	E	E	N	T	T	T	N	T	T	N	√			√	√√
		.2 Antenna Test and Calibrate	E	N	H	H	H	H	E	E	T	N	T	T	√	E	E	E	H	N	E	E	H	E	H	T	T	T	N	T	N	N	√			√	√√
		.3 Component Repair and Replace	E	N	H	N	N	N	N	T	E	N	T	T	√	E	E	E	H	E	E	E	E	E	H	T	T	T	N	N	N	T	√			√	√√
		.4 Environment Effect Inspection	E	N	N	N	N	N	N	T	T	N	T	T	√	E	E	E	H	N	E	E	E	E	H	T	T	T	N	N	T	N	√			√	√√
		.5 Inspection of Flexible Structures	E	N	N	N	N	N	E	T	T	N	T	T	√	E	E	E	H	N	H	E	E	E	H	T	T	T	N	T	N	N	√			√	√√
	5.1.2.4.16 Demonstration and Test	.1 System Simulation	E	H	H	H	H	H	H	H	H	E	H	H	√	N	H	N	H	H	N	H	N	H	N	T	T	T	T	T	T	T	√	RELAY TDRS, ATS LES, TIROS TACSAT		√	√√
		.2 Test Subsystem in Orbit	E	H	H	H	H	H	H	H	H	E	H	H	√	H	H	N	H	N	N	H	H	H	N	T	T	T	T	T	T	T	√	ATS, LES		√	√√
		3 Environment-Materials Validation	E	N	N	N	N	N	E	E	E	N	E	E	√	E	E	H	H	N	H	H	E	F	H	T	T	T	T	T	T	T	√	ATS, LES OV5		√	√√
5.1.3 Resource Management	5.1.3.2 MM Wave Demonstration	.1 Space-to-Space Links	E	N	E	N	T	T	N	E	N	N	N	N	√	H	H	N	H	N	N	H	H	H	N	T	T	T	N	N	T	T	√	ATS-F		√	√√
		2 Space-to-Ground Links	E	H	E	H	T	T	N	E	N	E	N	N	√	H	H	N	H	N	N	H	H	H	N	T	T	T	N	N	T	T	√	ATS-F		√	√√
		.3 High Data Rates	E	N	E	H	T	T	N	E	N	H	N	N	√	N	N	N	H	N	N	H	H	H	N	T	T	T	T	N	T	T	√			√	√√
	5.1.3.3 Optical Frequency Demonstration	1 Space-to-Space Links	E	N	E	N	T	T	N	E	N	N	N	N	√	H	H	N	H	N	N	H	H	H	N	T	T	T	N	T	T	T	√	ATS-F		√	√√
		2 Space-to-Ground Links	E	H	E	H	T	T	N	E	N	E	N	N	√	H	H	N	H	N	N	H	H	H	N	T	T	T	N	T	T	T	√	ATS-F		√	√√
		.3 Position Determination	E	N	E	N	T	T	N	E	N	E	N	N	√	H	H	H	N	H	H	H	H	H	N	T	T	T	T	T	T	T	√	ATS		√	√√
		4 High Data Rates	E	N	E	H	T	T	N	E	N	H	N	N	√	N	N	N	H	N	N	H	H	H	N	T	T	T	T	T	T	T	√			√	√√
5.2 Navigation and Air Traffic Control; 5.2.1 Space Needs	5.2.1.1 Earth Oriented Systems	.1 Satellite Relay of Range, Range Rate	E	E	E	H	T	N	N	H	N	N	N	N	√	N	H	H	H	H	H	H	H	H	H	T	T	T	T	T	T	T	√	ATS F, G		√	√√
		4 Laser Ranging	E	E	E	H	T	T	N	N	N	N	N	N	√	N	H	H	H	H	H	H	H	H	H	T	T	T	T	T	T	T	√			√	√√
	5.2.1.2 Autonomous Navigation Systems	3 Planetary Position Observation Against Fixed Background	E	N	E	H	T	T	H	H	U	N	N	U	√	H	H	E	H	E	E	H	N	E	H	N	N	N	N	T	T	N	√	APOLLO		√	√√
		4 Star Occultations by Nearby Planets/Satellites	E	N	E	N	T	T	H	H	U	N	N	U	√	H	H	E	H	E	E	H	N	E	H	N	N	N	N	T	T	N	√			√	√√
		5 Mode Handover for Interplanetary Cruise	E	N	E	H	T	T	H	H	U	N	N	U	√	H	H	E	H	E	E	H	N	E	H	N	N	N	N	T	T	N	√			√	√√
5.2.2 Aircraft and Marine Needs	5.2.2.1 Navigation (Passive and Active Systems)	1 Doppler Only Navigation	E	H	H	H	T	N	N	N	N	H	N	N	√	N	H	N	H	H	H	N	N	H	H	T	T	T	T	T	T	T	√	ATS-E		√	√√
		.2 Range Difference Employing Three or More Satellites	E	E	H	H	T	N	N	N	N	H	N	N	√	N	H	H	H	H	H	H	H	H	H	T	T	T	T	T	T	T	√	ATS-F/G		√	√√
		3 Angle Measurement from Two Satellites	E	E	H	H	T	N	N	H	N	H	N	N	√	N	H	H	H	H	H	H	H	H	H	T	T	T	T	T	T	T	√	621B TRANSIT		√	√√
		4 Angle Measurement from Single Satellite	E	E	H	H	T	N	N	H	N	H	N	N	√	N	H	H	H	H	H	H	H	H	H	T	T	T	T	T	T	T	√			√	√√
		7 Angle and Range Measurement	E	E	H	H	T	N	N	H	N	H	N	N	√	N	H	H	H	H	H	H	H	H	H	T	T	T	T	T	T	T	√			√	√√
		.8 User Transponds Range Signals Through Three or More Satellites	E	E	H	H	T	N	N	N	N	H	N	N	√	N	H	H	H	H	H	H	H	H	H	T	T	T	T	T	T	T	√			√	√√
		.10 Angle Measurement From Two or More Satellites	E	E	H	H	T	N	N	H	N	H	N	N	√	N	H	H	H	H	H	H	H	H	H	T	T	T	T	T	T	T	√			√	√√
	5.2.2.2 Surveillance	1 Range Transmitted from User to Control Center	H	E	H	H	T	T	N	N	N	H	N	N	√	N	N	N	N	N	N	N	N	H	H	T	T	T	N	T	N	T	√	Location/Identification Technique Feasibility Experiments		√	√√
		2 Position Reporting from User Via Satellite	E	E	H	H	T	T	N	N	N	H	N	N	√	N	N	N	N	N	N	N	N	H	H	T	T	T	N	T	N	T	√			√	√√
	5.2.2.3 Collision Avoid.	3 Beacon Transmissions by All Spacecraft on Same Frequency	E	E	H	H	T	T	N	N	N	H	N	N	√	N	N	N	N	N	N	N	N	H	H	T	T	T	N	T	N	T	√			√	
	5.2.2.5 Search and Rescue	1 Angle Determination from Low Altitude Satellites	E	E	H	H	T	H	N	H	N	H	N	N	√	N	N	N	N	N	N	N	N	H	H	T	T	T	N	T	N	T	√			√	√√
		.4 Rescue Operations Control and Coordination Communications	H	E	E	H	T	T	N	N	N	H	N	N	√	N	N	N	N	N	N	N	N	H	H	T	T	T	N	T	N	T	√			√	√√

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natural noise may have a significant dependence on meteorologic conditions, the necessity of collecting data over a long period becomes apparent.

Manned space research facilities appear justified, in preference to automated spacecraft, for communication and navigation experiments in earth orbit because many of the experiments would be very difficult to accomplish in automated satellites. In particular, many measurements require direct experimental control. For example, final selection of processing bandwidths requires examination of preliminary data prior to continuous and automated collection of data.

The experimenter's specific participation during space measurements may require that he perform one or more of the following listed activities (reflected in the general criteria described in Subsection 3.1.2):

1. Assemble, install, align, calibrate, operate, and maintain precision electronic equipment; exchange or replace such items as components, tuners, and recorders for different measurements.
2. Align, calibrate, and point large-aperture antennas; change feeds, install, boresight, examine, repair, monitor, and record.
3. Perform such tasks as filter and bandwidth changes, correct star pointing errors if acquired on wrong reference (with manual override), observe degradation thresholds of sensor and surveillance devices, and visually or electronically fix pointing cross hairs on targets selected for acquisition.
4. Operate hand-held autonomous navigation devices, and use TV or cameras to record experiment activity.
5. Search, scan, and acquire narrow-beam signals (i.e., optical laser transmitter).
6. Conduct simultaneous band transmission tests to compare and verify performance with theoretical predictions.
7. Observe effects of plasma (on communication system) during reaction control system or main propulsion firing.
8. Correlate observations across broad bandwidths (not easily automated) to obtain performance statistics.

9. Determine error source statistics to separate sensor errors from attitude and position inaccuracies that are incorporated in total system errors, including the influence of the environment. This may require onboard data processing and reduction.
10. Observe reliability and component degradation of communication equipment in space.
11. Inspect connectors for cold welds, shorts, and other anomalies.
12. Simulate planetary mission activities, such as evaluating long-range transmission performance, life tests, and thermal effects.
13. Perform manual navigation with simple instruments by manipulation, leveling, boresighting, and measuring angles, and compare the results with automated techniques.
14. Perform routine checks of system operations involving equipment test setup; adjust, modify, or vary the control conditions as necessary; monitor performance; and perform switchover functions.
15. Execute the test decisions and override automated measurements on the basis of location and time or as a function of surface weather conditions, etc., to reduce the quantity of data taken. This may involve pattern or feature recognition of ground tracks.
16. Operate detection and tracking equipment on detached modules and determine personnel proficiency in precision maneuvering of the spacecraft.

The review of the critical issues in terms of the manned versus automated screening criteria is also shown in Table 3-35, in the 17 columns under the heading "Manned Space Research Selection Criteria." A tally of the entries in this table shows that at least one orbital characteristic is essential to each of the 90 critical issues reviewed, and that the space environment is essential to the measurements for 36 of the critical issues. In several of the cases, in which the critical issue is concerned with the effect of the space environment on communication and navigation signals, the space environment is essential to the measurements because it is the subject of investigation. A numerical summary of the selections made in Table 3-35 is shown in Table 3-36.

TABLE 3-36

SUMMARY OF SCREENING OF CRITICAL ISSUES IN COMMUNICATIONS AND NAVIGATION

	Subobjective	Number of Critical Issues	Space Selection Criteria: Number for Which At Least One Orbital Characteristic Is Essential	Space Selection Criteria: Number for Which At Least One Environmental Characteristic Is Essential	Manned Space Selection Criteria: Number in Which Man's Participation As Scientist or Observer Is: Essential	Number in Which Man's Participation As Scientist or Observer Is: Helpful	Number in Which Man's Participation As Development Engineer Is: Essential	Number in Which Man's Participation As Development Engineer Is: Helpful	Number in Which Man's Participation As Technician Is: Essential	Number in Which Man's Participation As Technician Is: Helpful	Flight Safety: Number in Which Experiment Is a Potential Hazard to Flight Safety	Mission Performance Degradation: Number in Which Man's Presence Is Potentially Intolerable to the Experiment
5.1 Communications	5.1.1 Applications	12	12	1	0	4	0	4	0	8	8	0
	5.1.2 Research and Development	54	54	28	6	51	6	46	6	50	0	2
	5.1.3 Resource Management	7	7	7	0	7	0	7	0	7	0	0
	Subtotals	73	73	36	6	62	6	57	6	65	8	2
5.2 Navigation and Traffic Control	5.2.1 Space Needs	5	5	0	3	5	3	5	3	5	0	[illegible]
	5.2.2 Aircraft Needs	12	12	0	0	7	0	7	0	12	0	[illegible]
	Subtotals	17	17	0	3	12	3	12	3	17	0	[illegible]
	Totals	90	90	36	9	74	9	69	9	82	8	2

Three participation roles for the experimenter were examined as part of the manned space selection criteria, those of (1) scientist or observer, (2) development engineer, and (3) technician. Although man was judged to be essential in only nine of the critical issues, he was found to be helpful in a very large number of them (74 as an observer, 69 as a development engineer, and 82 as a technician). This judgment was influenced to a large extent by consideration of a given line of investigation in the context of the neighboring critical issues that may be related. A great deal of common equipment observed during this review may be involved, depending upon the utilization or observation of adjacent frequency bands and upon the baseband processing equipment required. The predominance of cases in which man, although not essential, could make a significant contribution to the effectiveness of the required research, was instrumental in arriving at the conclusion that manned experimentation is justified and perhaps essential to the success of an overall research program. This judgment was made in full realization of the fact that any single-point experiment could be automated. Conversely, man would be useful or helpful in setting up general-purpose test equipment in a variety of experimental configurations.

The alternative to the above approach, which may be described as a philosophy of laboratory experimentation, would be a series of automated spacecraft with broad capabilities in communication and navigation research. Each of these automated spacecraft would be configured to include a series of experiments with limited objectives. The latter approach is representative of the present philosophy of the NASA Communications and Navigation program for space experimentation, and there is no question as to its feasibility. The principal argument against this philosophy of space testing, assuming that manned space research facilities will be available within the foreseeable future, is the large time lag between initial observations and follow-on experiments. When viewed in light of the large number of unknowns presently identifiable, as well as the large benefits to be achieved through enhanced utilization of space communication satellites, the adaptation of a laboratory philosophy of communication and navigation testing (as opposed to a fully automated testing program) offers substantial tradeoffs in the acceleration of the development of space communication and navigation systems. Whether one philosophy or the other is actually superior on a cost-to-benefit basis must remain for further analysis.

Two additional criterion groups were examined:

1. Mission performance degradation caused by the presence of man.
2. The potential hazards to the safety, physical health, and mental health of experimenters in space.

For two of the 90 critical issues reviewed, it was considered that the perturbations due to man's presence in the spacecraft would probably degrade the experimentation. These two critical issues both deal with the environment of space communication repeaters, and the quality of research observations may be influenced or degraded because of effluent release from the spacecraft. Thus, these particular critical issues may not be suitable for investigation onboard the manned space research facility, but as an alternative may be subject to investigation by deploying separate experiment modules or subsatellites. Therefore, these two issues (5.1.2.2.5.1, Pressure Change versus Time, and 5.1.2.2.5.2, Charge Density) have been coded Potentially Intolerable in Table 3-35, but they are still retained for subsequent manned flight. This reduced to 88 the total number of critical issues where man's presence was judged to be helpful to the research involved.

The research activities suggested by eight of the critical issues were also judged to be potentially hazardous to man. These eight critical issues occur in the applications area. The considerations that led to their rejection were very high voltages, high RF power densities in the spacecraft vicinity, and high radiation exposures, particularly in cases where high-altitude or synchronous orbit would be required. Again, despite the code of Intolerable, careful experiment design should overcome these handicaps, and the eight issues so marked were therefore retained for manned space flight.

It was mentioned previously that man's participation was judged essential to the experiments in all five of the critical issues listed under Contributions of Manned Space Flight to Technology Development (5.1.2.4.14); to one of the three critical issues in a demonstration task, (Space Qualification of Components, 5.1.2.4.16.3); and to three critical issues dealing with Autonomous Navigation Systems (5.2.1.2). The five critical issues under 5.1.2.4.14 deal with separate activities that man may perform in space and are therefore concerned primarily with astronaut capability and only secondarily with communication and navigation. Operations or support activities of the experimenters that have been identified for critical investigations are as follows (reference Appendix B):

5.1.2.4.14.1 Antenna Deployment
5.1.2.4.14.2 Antenna Test and Calibration
5.1.2.4.14.3 Component Repair and Replacement
5.1.2.4.14.4 Environment Effect Inspection
5.1.2.4.14.5 Inspection of Flexible Structures.

These activities would generally contribute to the conduct of a wide variety of communication and navigation experiments, even if man's contribution might not be essential to any single experiment considered individually. It should be noted that similar critical issues are identified under Manned Space Flight Capability in the areas of engineering and operations research. Research clusters I-EE-4 and -5 are notable examples in technology, and I-OE-2 and -3 in operations experiments.

The three critical issues under navigation where man was judged essential are primarily concerned with development or refinement of new navigation techniques for application on both manned and automated spacecraft. For employment on manned spacecraft with an astronaut navigator, man becomes an integral part of the experiment by functioning as a control element.

Under Technology Demonstration and Test (5.1.2.4.16), three critical issues were examined. These issues addressed three levels of qualification testing as a necessary part of system research and development. This review of man's utility in the space testing of communication and navigation systems has led to a general recommendation on conceptual approach, which is best illustrated by the retention of the critical issue related to Space Qualification of Components (5.1.2.4.16.3). The three levels of development testing considered were (1) system simulation (including spacecraft subsystems and other terminals), (2) test of subsystems in orbit (subsystem complexity to range from modulator or memory to a complete spacecraft), and (3) multiple tests of single components, leading to performance demonstration and flight qualification. Comparing these three levels, as the number of devices to be tested and the number of tests to be performed on each item increases, man would be more useful in the experiments at the lower levels of the system tests. At the system test level, on the other hand, so little crew time is required for operational demonstration and for the minimal number of component adjustments that a system task is better performed using automated spacecraft.

The above general observation may also be applied to the large number of critical issues that on an individual basis did not survive the requirement that man be essential to the experiment. Many of the propagation critical issues have been, and will probably continue to be, pursued by relatively small automated spacecraft. These small experiments, however, which were begun on some of the earlier spacecraft, have yet to fulfill the wide range of information needs in such categories as tropospheric effects, ionospheric effects, plasma effects, and radio-frequency interference. As a result of a comprehensive analysis of sets of critical issues, a major conclusion was reached that manned orbiting vehicles generally equipped for a wide variety of experiments could make a highly advantageous contribution to the development of advanced communication and navigation systems in space.

The manned facility is envisaged as containing a variety of compatible test instruments and system components that could be configured for use in many possible experiments. In this way, many of the critical issues where man may be judged as being only helpful but not essential can also be addressed systematically. Since in many respects the manned and automated approaches would complement each other, it will be necessary to evaluate the general-purpose manned test facility on the basis of whether automated spacecraft alone can generate required engineering data rapidly enough.

3.6.3 Contribution of Ongoing Programs

The principal source for information on ongoing, unmanned NASA programs was the preliminary draft document prepared by OSSA, "Communications and Navigation Program Documentation," dated 1 May 1969. These programs are divided into communication research and development, broadcasting, tracking and data relay satellite systems, information networks, data collection, and navigation and traffic control. Program elements described were chiefly for automated systems and were screened for relationships with the 90 critical issues found suitable for space research. It was concluded that manned orbital experimentation offers many opportunities to expand beyond the specific point measurements assigned to NASA's automated communication and navigation technology satellites.

An example is found in laser communications. The ATS-F spacecraft mission contains a number of space-to-ground and space-to-space measurements using a 10.6-micron laser system.* The automated satellite which will be launched during 1973, is expected to perform many difficult measurements, as shown in Table 3-37. This single-point experiment, however, is only a preliminary step in resolving fundamental problems inherent in space laser technology. As the state-of-the-art advances, other spectral wavelengths will undoubtedly be tested as newer laser materials become available. With the development of competitive systems, the use of laser hardware will require space demonstration and evaluation of overall efficiency and reliability of operation.

The evolutionary nature of this example of communication experimentation in space dictates a need for continuing technology development to improve system applications. In this regard, the program recommended to explore the broad areas of propagation, noise, and radio frequency interference; component qualification in space; and system concept demonstration encompasses an array of space laboratory measurements across the entire electromagnetic and optical spectrum. The basic approach, therefore, has been to recognize the contribution from ongoing, unmanned space point experimental data as being complementary to a broadly based manned investigative program. Consequently,

*10.6-Micron Laser Communication System Experiment for ATS-F/G, GSFC Report X-524-68-206, May 1968.

TABLE 3-37

LASER EXPERIMENT FOR ATS-F AND ATS-G

Experiment	Measurements	System Apparatus
10.6 Micron Laser Communications (ATS-F) (Reference critical issues: 5.1.3.3.1, 5.1.3.3.2, 5.1.3.3.4)	Determine communications parameters (signal to noise, bit-error rate, system efficiency) Measure transmitter frequency stability and drift Determine receiver-noise bandwidth interrelation to L.O. AFC loop and dependence on frequency stability and Doppler shift Determine noise figure of radiation-cooled infrared detectors and mixers Determine background noise levels due to antenna pointing at Earth, sun, and other planets Measure telescope tracking servo loop parameters	Optical subsystem Coarse beam pointing mechanism 5-in. Cassegrainian telescope Image motion compensator Directive mirrors Beam splitters Laser subsystem 400-mw transmitter (CO_2) Modulator 50-mw local oscillator Frequency stabilization servo Power meters Detector subsystem Signal information detector Preamplifiers Image-motion detector Radiation cooler Signal processing subsystem IF postamplifier Image motion compensator drive electronics Transmitter modulator drive electronics Frequency control electronics Beam pointing electronics Command/telemetry interface Power supply subsystem High voltage Low voltage Drive electronics Signal processing

critical issues were not eliminated from further consideration purely on the basis of NASA's ongoing programs, although certain measurements are to be satisfied, as indicated in the next paragraph.

Figure 3-21, compiled from the previously mentioned preliminary OSSA document and from other available data, presents a summary of the known NASA programming in Communications and Navigation. The ATS-F and ATS-G experiments being planned appear to satisfy most of the requirements of 5.1.1.2 Broadcast, and several of the ATS satellites appear to have the inherent capability required for preliminary investigation of 5.1.1.3 Information Networks. The tracking and data-relay satellite now being planned seems to fulfill the initial requirements for 5.1.1.4 Data Collection. Thus, several experiments that appear to represent safety and phychological hazards on a manned spacecraft are at least partially satisfied by ongoing programs. This suggests a lower preference for utilizing a manned spacecraft for experiments in these areas, since automated satellites are already being planned, and each presents a design hardship for manned stations.

The critical issues derived in this study were reviewed and correlated with the NASA document, "Candidate Experiment Program for Manned Space Stations," (Blue Book, 15 Sept. 1969), which presents a number of manned experiment functional program elements (FPE's). Examination of the experiment tests described on the Blue Book indicates that Item 24B, Guidance and Control, under FPE 5.24, MSF Engineering and Operations, appear to satisfy Critical Issue 5.2.1.2.6, Stable Inertial Reference Platforms. With this exception, and those mentioned in the preceding paragraph, it appears that the critical issues are sufficiently broad and open-ended to require continuing research.

3.6.4 Grouping of Critical Issues into Research Clusters

3.6.4.1 Rationale for Grouping

As was seen in Table 3-36, only nine critical issues, six in Communications and three in Navigation, were accorded the judgment that the presence of man

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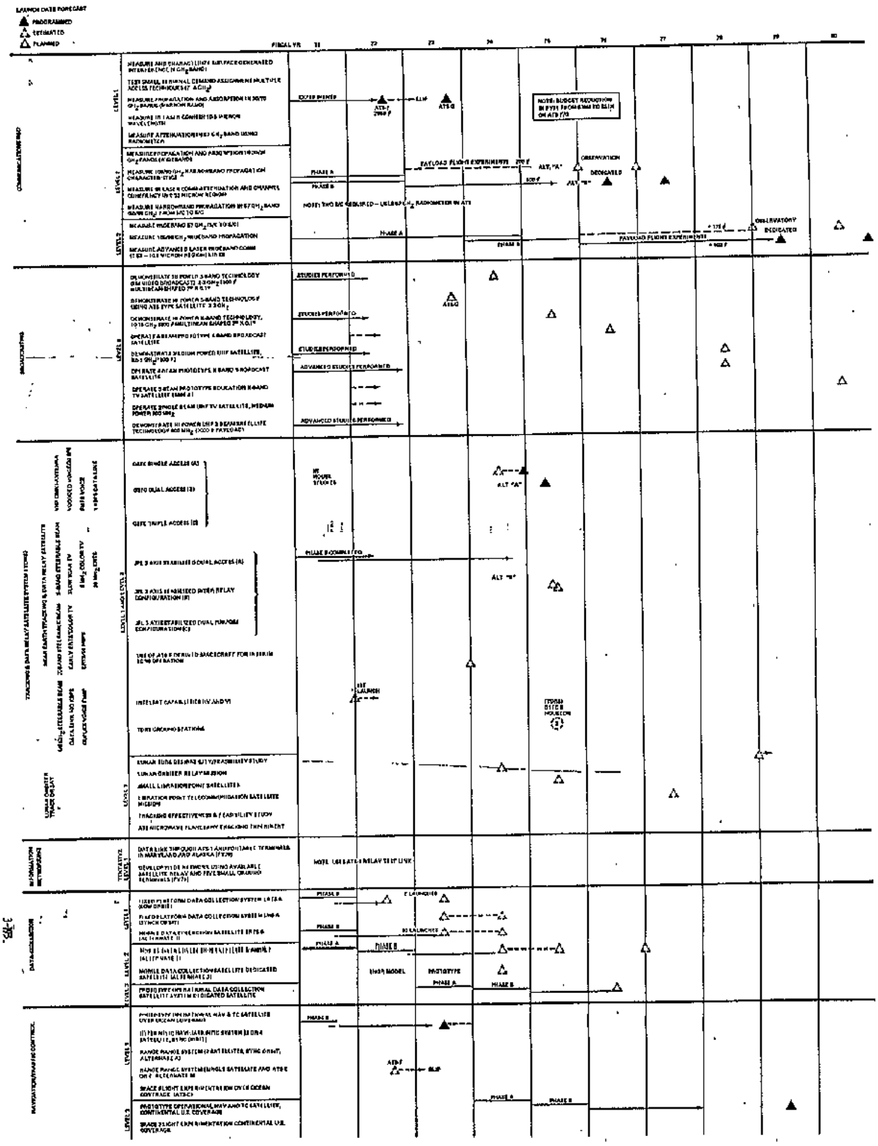

Figure 3-21. NASA Program Summary — Communications and Navigation

in space was essential in performing the related experiment. Of the six Communications issues so identified, five survived the screening because, in essence, the intent of the experiment is to test man's capability to perform selected operations rather than because the system that may result from such operation would in some way make a unique contribution to the discipline's central problem; namely, providing communication and návigation services to users. The sixth, space qualification of components, was retained because it involves testing of components and subsystems leading to flight qualification for automated systems.

Similarly, the three surviving critical issues under Navigation (i.e., Planetary Observation Against Fixed Background, 5.2.1.2.3; Star Occultation by Nearby Planets or Satellites, 5.2.1.2.4; and Mode Handover for Interplanetary Cruise, 5.2.1.2.5) address techniques and transition problems in navigation systems for manned spaceflight in which man would be a part of the system, either as a sensor or operator. Consequently, man is essential to the experiment.

While the approach and subsequent analysis clearly established the essential role of man for the nine critical issues discussed above, there is a secondary role of helpfulness, which could not be overlooked. The remaining 81 critical issues were therefore reexamined to determine whether man's presence would materially aid in the execution of space measurements. During a research phase exploring advanced communication and navigation systems for evaluation and testing, many of the measurements could be usefully conducted by a trained experimenter in space.

The evaluation of each of these critical issues led to a grouping of all potential measurements into 16 research clusters. These 16 research clusters, in turn, fell into five major functional groups as listed below.

Group 1 - NOISE

5-N-1 Terrestrial Noise Measurements

5-N-2 Noise Source Identification

Group 2 - PROPAGATION

5-P-1 Ionospheric Propagation Measurements

5-P-2 Tropospheric Propagation Measurement

5-P-3 Plasma Propagation Measurements

5-P-4 Multipath Measurements

Group 3 - TEST FACILITY

5-TF-1 Space Laboratory Deployment and Calibration

5-TF-2 Demonstration and Test (Techniques, Components, Systems)

Group 4 - COMMUNICATION SYSTEM

5-CS-1 MM Wave Demonstration

5-CS-2 Optical Frequency Demonstration

Group 5 - NAVIGATION SYSTEM

5-NS-1 Satellite Navigation Techniques for Terrestrial Users

5-NS-2 Laser Ranging

5-NS-3 Autonomous Navigation Systems for Space

5-NS-4 Surveillance Systems

5-NS-5 Collision Avoidance System Techniques

5-NS-6 Search and Rescue Systems

These five groups and the included sixteen research clusters identified under them retain the common features of all 90 critical issues that were judged as candidates for manned space experimentation. As explained previously, the two critical issues that were evaluated to be unduly influenced by the presence of man have been retained because the possibility exists for the use of remote modules in the manned space program. These experiments may not actually be performed at the manned space research facility but by subsatellites or modules controlled or configured in, and ejected from, the facility. Most of the measurement programs identified in the above listing have had some groundwork laid by previous automated satellites or are the subjects of NASA's ongoing programs. The previous and ongoing program data are regarded as the departure points of the experimental programs to be identified under the 16 research clusters named above.

Review of the research clusters will indicate that these research activities may not be characterized as isolated point measurements but are indeed continuing experimental programs. In many cases, only the initial experiment in these programs can be identified at this time. In describing such groups of experiments, it is necessary first to establish the objectives of the cluster group itself, and the most that can be done is to identify one or more research clusters that are clearly needed at this time. In such a listing, it is not practical to project the expected contributions of future automated space platforms to these research programs. This element should be the subject of continuing evaluation.

The research clusters in Groups 4 and 5 deal with the topics of advanced communication systems and navigation systems. The ultimate operational systems derived from these clusters will involve space repeaters and beacons flown as automated satellites. The research clusters emphasize technique experimentation leading to system demonstrations. Depending upon the maturity of the system under test, assigning the research either to a manned space laboratory or to the automated satellite research program will require resolution in terms of the time frame established for the measurements in question. The exact point of transition for the research remains a matter of judgment, although the primary manned research role supports only preoperational system testing. In laying out a framework for the original overview development, the subject of navigation and traffic control received special emphasis, although the system might well have been included in the general group of application programs rather than under a separate heading. However, the overview treatment is more compatible with the present NASA program functions.

Similarly, the characters of the two items under Group 3 are different from the remaining four experiment groups. These two items deal with Space Laboratory Deployment and Calibration, and with Demonstration and Test. This grouping results in describing a place for inclusion of all activities that are largely experimental in nature and that involve the evaluation of manned capability as it relates to the development of a communication and navigation laboratory facility in space. Although such evaluation may normally fall under the manned flight discipline in this study, since it is directly related to the communication experiments, the facility for it has been included as a separate group in the Communications and Navigation discipline.

In most cases, the titles of the research clusters have been taken from the titles of the subcategories of the next-higher level of the overview in which two or more critical issues appear. The list has also been somewhat simplified by assuming that critical issue 5.1.2.4.16, Demonstration and Test, includes four critical issues under 5.1.1.4 and six critical issues under 5.1.2.2.5. Similarly, the four critical issues under 5.1.2.4.2, Spacecraft Antennas, have been included under 5.1.2.4.14, Space Laboratory Deployment, Critical issue 5.1.2.3.4.7, Comparison of Noise and RFI Models With Observations, is identical to critical issue 5.1.2.2.1, Terrestrial Noise Measurements, and is included in that category.

Thus, there are 90 critical issues included in the above 16 research clusters, which implies that some have been included that are considered marginal from the safety standpoint. These questions are addressed in the research cluster descriptions.

3.6.5 Brief Descriptions of the Research Clusters

In summary, in the study discipline of Communications and Navigation, 16 research clusters were formed from the 90 critical issues judged to be suitable for a manned earth-orbital research program. A brief description of these research clusters is presented below. Additional descriptions may be found in Appendix C.

The basic grouping of objectives of each discipline is as follows:

A. Noise. Perform mapping of the apparent noise temperature of the Earth and locate and identify terrestrial sources of significant magnitude compared with the thermal background radiation for the purpose of planning and designing space communication systems.

B. Propagation. Investigate the RF transmission properties of the ionosphere, troposphere, and plasmas as they effect communication and navigation systems. Obtain measurements of the statistical properties of signals received via multiple paths and model means of predicting the effect of multipath signal reception.

C. Test Facilities. Provide manned space test laboratories to enable testing and calibration of advanced communication and navigation hardware. The space laboratories will also provide the capability for advanced concept testing of communications and navigation systems.

D. Communication Systems. Demonstrate, in space, millimeter wave and optical frequency communications systems and determine their performance limitations or physical constraints.

E. Navigation Systems. Demonstrate, in space, advanced satellite navigation systems for terrestrial users including those systems designed for aircraft and ship navigation, earth-bound vehicle surveillance, collision avoidance, and search and rescue. Demonstrate, in space, advanced systems for autonomous navigation of spacecraft as well as systems for rendezvous and docking.

To satisfy the objectives of the Communications and Navigation discipline requires a broad range of instrumentation types.

By providing the space test facilities to meet these broad objectives of measuring, testing, and demonstrating advanced communications and navigation systems and characterizing the propagation medium, the evolution period of operational systems for earth-space-earth relays, surveillance, data collection and dissemination, air traffic control, search and rescue, and space navigation will be significantly shortened with resultant economic and social benefits.

SUBDISCIPLINE SYNOPSIS

5-N

Noise: 5-N-1, 5-N-2

1. Research Objectives

The objectives of these research clusters are to map the apparent noise temperature of the earth as viewed by a spacecraft-mounted antenna and to geographically locate and identify terrestrial sources of electromagnetic radiation in the 0.1- to 100-GHz portion of the spectrum. Electronic oscillators and other noise generators that cannot be categorized by thermal equilibrium comprise the sources to be located and identified. Research will be performed in the following areas.

5-N-1. Mapping of terrestrial electromagnetic noise.

5-N-2. Location and identification of terrestrial sources.

Previous experimental work in this area has been done by radio astronomers measuring extraterrestrial radio sources as viewed from earth. Measurement of the spectral temperature distribution over the earth's surface, or mapping the ambient signal environment at various regions of the electromagnetic spectrum is an experiment that could be carried out from a spacecraft laboratory.

Accomplishment of the objectives is envisioned through the use of broad-bandwidth antennas, scanning receivers, and signal-processing equipment contained aboard a manned spacecraft. With this equipment and man's participation, the terrestrial signal environment signature may be collected and analyzed to determine interfering levels and associated modulation structures.

The resulting data would be of use in such tasks as the planning and designing of satellite and deep space communications, passive monitoring of electromagnetic activity, meteorological studies, and ionospheric studies.

The knowledge gained by pursuing this research will permit more efficient use of the spectrum, will aid in establishing frequency allocations and system standards, and will place the U.S. in an informed position regarding negotiations for international frequency allocations.

2. Background and Current Status

The ambient signal environment will have components ranging over the entire radio spectrum. The power spectral density of the energy will be a function of frequency, angle of arrival, and other source parameters such as emissivity.

The sources of the ambient signal environment can be broadly classified as follows:

1. Thermal terrestrial
2. Atmospheric (terrestrial)
3. Extraterrestrial
   A. Solar
   B. Planetary/lunar
   C. Cosmic
4. Man-made (terrestrial).

In general, the noise sources to be located and identified are man-made, specifically the spectrally discrete outputs of RF transmitters and the distributed spectra of random generators such as machinery. Because they are man-made, the geographical distribution of these noise sources tends to be concentrated in areas of high population density and industrial activity.

A considerable amount of equipment has been developed, especially for S- and X-band military missions, specifically for identifying the classes of known transmitters (commercial and industrial broadcast stations, radars, and certain varieties of industrial equipment). The equipment can generally be categorized as being the spectrum analysis class.

3. Description of Research

In measuring the terrestrial noise temperature from a spacecraft, the basic observables are antenna temperature, the antenna pointing angles, orbit position, and the frequency band to which the receiver is tuned. The research can best be described as that of mapping the earth with a wide-bandwidth radiometric receiver, an antenna-receiver combination that produces an output signal proportional to the temperature of the object within the antenna pattern.

Noise-source location and identification may be achieved by obtaining the signature of the emitter and its geographical coordinates. This is accomplished through the use of narrowbeam broad-bandwidth antennas, panoramic receivers, and appropriate signal-processing equipment.

Requirements may be established from the relationship of signal-to-noise ratio (S/N), antenna beamwidth ($\Delta\Omega$), and dwell time (τ) of the antenna beam at a given position on the earth. This latter parameter depends upon spacecraft orbit characteristics. These three quantities form a triple product, which has a constant value:

$$S/N \cdot \Delta\Omega \cdot \tau = \text{constant} .$$

If the antenna beam is made very narrow, giving great precision in emitter location, the dwell time also decreases, making it necessary for the signal level of the emitter to be large. That is, under such circumstances "weak" emitters will be identified with uncertainty. To make this model slightly more realistic, the additional variable of carrier frequency can be added. This is equivalent to dividing up the dwell time per spatial resolution element into intervals within which a frequency search must also be carried out. Other such variables can also be added.

Noise measurements should be made at about 3-hour intervals, at least over locations that are likely to be covered by Comm/Nav satellite systems. Such measurements extending at least over a calendar year would be desirable.

The equipment required consists of antennas and receivers operating in the regions of the Comm/Nav satellite frequencies. The data consists of a signal that represents the antenna temperature of the instantaneous resolution element, averaged over the antenna beam's footprint within the receiver bandwidth. These data must be recorded and related directly to the pointing angle and geographical location so that contours of given levels of noise power can be constructed.

The frequencies used should be the ranges corresponding to present and foreseen Comm/Nav system usage.

136 MHz - 150 MHz
300 MHz
1700 MHz - 1800 MHz
2250 MHz - 2300 MHz
3700 MHz - 4200 MHz

5925 MHz - 8400 MHz

16 GHz

32 GHz

4. Impact on Spacecraft

The spacecraft orbit inclination should be 90 degrees to provide global coverage. Orbit altitude should be between 200 and 1000 nmi, as a compromise between acceptable drag and antenna structure size. Ground resolution is a function of antenna aperture. Spacecraft attitude stability should be within 0.1 degree, and the attitude determination system should provide $\pm$ 10 arc-sec pointing accuracy of the antennas. Orbit determination should provide $\pm$ 1-nmi ground location accuracy.

The role of man in this experiment will consist of configuring the spacecraft receivers and monitoring the data outputs. As the experiment proceeds, it may become necessary to make certain changes; for example, post-detection integration time constants, and temperature of the radiometer calibration source. The use of a large space-erectable antenna would require EVA and special training.

5. Required Supporting Technology Development

To perform the experiment efficiently; i.e., to maximize the spectrum width observed per unit time, special receivers and antennas with high-speed switching of frequency bands is required.

A major technological area that requires further development is that of signal processing, data sorting, and hard-copy production, specifically for signal mapping. Another fundamental problem is that of maintaining or at least compensating for the variation in resolution over the necessarily broad frequency spectrum covered in the experiment.

SUBDISCIPLINE SYNOPSIS

5-P

Propagation: 5-P-1 through 5-P-4

1. Research Objectives

The objectives of this research cluster are to:

A. Measure the effects of the troposphere on RF propagation parameters, specifically the effects of water vapor and molecular oxygen content upon attenuation, phase, and refraction as a function of frequency. Since the constituents of the troposphere are spatially and temporarily distributed random variables, the objective is one of determining the statistics of propagation along various path lengths; elevation angles; and time of year, season, climate, and weather conditions.

B. Investigate the RF transmission properties and structure of the ionosphere to develop more precise ionospheric predictions. These properties include the spatial and temporal distribution of electron density, which in turn effects attenuation, refraction, coherent bandwidth, and polarization rotation of electromagnetic waves propagating through the medium.

Investigate the feasibility of transmitting signals from reentry vehicles to a relay satellite instead of to the ground, thereby avoiding the problems associated with transmission through the high-density portion of the plasma produced by the frontal shock wave.

Measure statistical properties of signals simultaneously received over multiple propagation paths between terrestrial users and spacecraft for all frequencies proposed for space repeater communication and navigation systems. Obtain fundamental data for predicting multipath signal reception as a function of aircraft attitude, elevation angle to the signal source, and the type of terrain.

2. Background and Current Status

The effects of the earth's atmosphere on the propagation of both electromagnetic wave and optical wave have been studied in theory and in experiments by many investigators. The one observation that seems common to all of the studies is the nondeterministic nature of the processes that contribute to the phenomenon, since there are virtually an infinity of possible atmospheric conditions, each of which can be described only in a statistical manner with reference to the effects on propagations at both microwave and optical frequencies. To help overcome this seemingly intractable analytical problem, the effects may be described in terms of three basic functions: attenuation, refraction, and atmospheric noise.

Before RF transmission systems can be designed that call for use of certain frequencies in the earth's atmosphere statistical data must be available; for example, on the percentage of the time when the attenuation in a given frequency range exceeds 10, 20, or 30 db. Such data must be known for a variety of locations, weather conditions, and satellite-ground terminal geometries.

Attenuation of RF signals by the thermally ionized atmosphere (plasma) surrounding a reentry vehicle is of principle concern, not only because of loss of communication during the "blackout" period but also because of the appreciable length of time during which it occurs.

The frequency range over which the maximum attenuation occurs is from 10 to 10.8 MHz. Consequently, the main approach to avoiding the blackout problem has been to use frequencies either lower or higher than this band; e.g., X-band. Such systems have not been operationally implemented. Use of communication relay satellites as an indirect path is suggested as a feasible solution approach to the blackout problem.

Communication links involving satellites and aircraft with relatively widebeam antennas encounter multipath transmission and fading, especially where the aircraft is at high attitude and over water. The situation is probably most severe when the satellite is near the horizon as viewed from the aircraft. Similarly, the effects of multipath must be considered when a signal transmitted from a user satellite is scattered by the Earth before reaching a tracking and data relay satellite (usually in stationary orbit). The problem in this case is that scattered signals interfere with the signal that proceeds directly from the user satellite to the relay satellite.

To date, very little experimental data exist on the nature of the multipath or the fading experienced over the aircraft-to-satellite communication link although some work has been done, utilizing L-band and VHF-UHF satellites.

3. Description of Research

The distribution of electron density in the ionosphere will be measured by the use of ionospheric sounding (ionosounders) located in the spacecraft. Ionospheric sounding allows time resolution and continuity-the sensitivity and dynamic range required of an effective method of measurement. This involves the transmission of an RF pulse (at the frequency at which the ionosphere's characteristics are desired) and the measurement of the received backscattered signal strength.

The methodology consists of processing the received backscattered signals, which are a function of space (antenna arrays and pointing angles), time of transmission from the spacecraft, and frequency of the transmitted signal.

An extension of normal top-side sounding methods will involve the use of sub-satellites to sense the sounder signal and to perform localized soundings in an attempt to obtain three-dimensional, nearly simultaneous profiles. One or more subsatellites may be placed in various orbits for relaying the ionograms. The sounding experimental methodology will involve transmission of a radio pulse at various desired closely spaced frequencies into the ionosphere and recording until the desired range of frequencies is covered. Further detail on local electron density and horizontal structure is obtained by receiving the sounder signals at the subsatellite.

In the lower frequency region, such as VHF or UHF, many tropospheric effects on earth-to-space communications are well understood, and can therefore be either compensated or neglected. However, there still exists an unsolved problem regarding the random fluctuations in the dielectric constant of the troposphere. These fluctuations will cause random scattering of the wave, and therefore introduces variations in the amplitude, phase, angle of arrival, and polarization of the wave. In the future communication system design, it seems certain that higher-frequency systems, such as millimeter wave and optical frequency bands will be predominant. Unfortunately, the effects of the fluctuations in the dielectric constant are most pronounced at these frequencies.

For plasma propagation research, tracking antennas and receivers in the space vehicle or experiment module corresponding to the chosen set of transmitters in the reentry vehicle must be configured. Within the reentry vehicle, certain quantities must also be measured and recorded. Principal among these are the complex VSWR at the transmitting antenna during reentry, vehicle attitude, and altitude history. It is assumed that the geometry and composition of the reentry probe are known. It might be useful for the probe to be furnished with a mass spectrometer to obtain an _in situ_ measure of outgassing species, which would contribute to the ionization. Vehicle altitude, as well as velocity profile and meteorological conditions, can be obtained from simultaneous ground observations. The space observation platform (station or experiment module) will contain recorders and telemetry equipment for either realtime or delayed transmission to ground data-readout terminals.

The multipath research will be conducted at various frequency bands in the air traffic user environment, with the spacecraft transmitter operating at several altitudes and orbital inclinations, and with the receiver equipment located in jet-transport user-type aircraft. The flight path will include multiple flights over various terrains and with different geometries of the receiver aircraft with respect to the spacecraft. A receiving-antenna configuration for VHF, L-band, and X-band is required on the spacecraft for the multipath signal measurements. The link tests will be conducted over all kinds of terrain, including oceans in different sea states. Data from the multipath receivers will be recorded on the aircraft and processed postflight , along with the overall simulation of the system.

4. Impact on Spacecraft

The altitude extent of the ionosphere (50 to 1000 km) suggests that a low-orbit spacecraft, such as the space facility or experiment modules serve as the platform for this research cluster. In fact, the remote maneuverable subsatellite (RMS) defined in the Blue Book is ideally suited for the role of the subsatellite in this research.

Steerable antennas would be required on the spacecraft, but the pointing accuracy would not be stringent, perhaps 1 degree. Station keeping is not critical, but the spacecraft orbital position at the time of measurement was taken is important for correlating with other observables. Attitude control is necessary only as far as it affects antenna pointing.

To avoid the problems of signal acquisition, Doppler tracking, and antenna-angle acquisition and pointing on the spacecraft, a stationary synchronous orbit is recommended. The orbit position should be such that ground stations may be located conveniently to allow elevation angles of perhaps, 5, 7-1/2, 10, 15, 20, 30, 45, 60 and 90 degrees. Large-aperture antennas may be required on the spacecraft, particularly at lower frequencies to enable measurement of the angle of arrival. Spacecraft attitude should be known within 0.05 degree, and its position should be known within 0.01 nmi.

5. Required Supporting Technology Development

Maximum use will be made of current research and technology programs, such as ISIS-1, ISIS-B, ISIS-C, and Alouette. Experiments will complement these ongoing programs, and as a result, no new supporting research and technology may be required.

The plasma propagation research would be more useful if coincidentally, the effects of physical and chemical means of modifying reentry plasmas were evaluated.

Although not directly a portion of the considerations here, the problem of designing antennas that can survive the range of alternative reentry conditions is important.

SUBDISCIPLINE SYNOPSIS

5-TF

Test Facilities: 5-TF-1, 5-TF-2

1. Research Objectives

The objective of this research cluster is to provide a manned spacecraft facility to fulfill the required test and calibration functions of communication and navigation equipment as well as the deployment (erection, alignment, and test) of space antenna structures.

Another objective is to provide the basic facility in which ultimate communication and navigation systems, subsystems, materials, and procedures may be fully tested and validated in the end-use space environment prior to operational deployment.

Essentially, the objective is to develop a versatile, manned space-borne laboratory with most of the features of its ground-based counterpart, plus the unique features offered by the ambient environment of space; e.g., the realism of system performance testing afforded by evaluating the equipment in the configuration (relative geometry, etc.) intended for operational use.

Development and manned operation of the space laboratory facility will, in itself, comprise a sophisticated advanced technology experiment aimed at investigating means of experiment integration, which are significantly independent of experimental definition.

2. Background and Current Status

Each of the 14 scientific research clusters includes equipment comprised of various sensors, antennas, receivers, recorders, etc., which require initial and periodic calibration and test. Some of these research clusters; notably, 5-N-1, Terrestrial Noise Temperature; 5-N-2, Noise Source Identification; 5-P-1, Troposphere Propagation Measurements; 5-P-2, Ionosphere Propagation Measurements; and 5-P-4, Multipath Propagation Effects, require the erection, alignment, test, and calibration of large antenna structures. To accommodate the frequency range required in these experiments, changeable antenna feeds have been proposed, which if implemented will require extravehicular installation and must be recalibrated before the experiment begins. Consequently, a space laboratory dedicated to the research clusters mentioned above and with the requisite support capability is desired.

It is apparent that it will be impossible to resolve all 90 Communications and Navigation critical issues having potential for space experimentation onboard a single configuration of an orbiting space laboratory. Potentially important is the capability to accommodate the test and demonstration requirements of the remaining critical issues not yet meeting the immediate criteria for potential space experimentation.

3. Description of Research

In the assembly and preparation of experiment apparatus, the initial checkout will require apparatus calibration. This may also entail some external activity (EVA) to erect antennas, install feeds, interconnect components, and make preliminary baseline measurements. The exact treatment of particular experiments depends on a thorough preplanning of astronaut activities for each research grouping. The methodology used necessitates that a detailed experiment design and the preparation of a test plan and procedures be followed. Reliable astronaut performance may require substantial training of the precise measurement techniques and an understanding of the parameter's sensitivity to fluctuations when in a changing space environment. The general space laboratory facility must be equipped to support each of the experimental group requirements assigned to a given mission.

4. Impact on Spacecraft

Essentially, the requirements that evolve from this research cluster comprise the requirements for a space facility. The laboratory facility should be equipped to enable the astronaut to conduct equipment transfer, setup, erection, assembly, interconnect, and calibration actions prior to beginning the experiments. The variety of experiment measurement parameters is identified in each of the 14 research cluster descriptions.

The payload for the test facility in terms of test and measurement equipment must reflect the current grouping of experiments to be performed, and meet the accuracy, range, and interface requirements of the measurements specified in each grouping.

5. Required Supporting Technology Development

The requirements of each of the 14 research clusters are described separately in Appendix C. Erection of antennas used by these experimental configurations may require EVA, and particular techniques used will depend on a selection from many possibilities. Special handling procedures, tools, and even remote manipulators (teleoperators) may be employed for placing and removing externally mounted components.

SUBDISCIPLINE SYNOPSIS

5-CS

Communications Systems: 5-CS-1, 5-CS-2

1. Research Objectives

The basic objective of this research cluster is the acquisition of data for the evaluation of millimeter-wave and optical-frequency system techniques and system components under realistic environmental conditions. Although programs are currently under way for evaluation of the earth's atmosphere as a propagation medium, the proposed experiment will provide a means of obtaining supplementary data and will permit wide variation of system parameters to obtain additional information.

The objectives of this research are to:

1. Refine and extend the knowledge and range of data associated with the use of optical and millimeter wave frequencies in space communication applications.
2. Ascertain the practicality of wideband, high-data-rate communications between a spacecraft in nonsynchronous orbit and a ground station, and between two orbiting spacecraft.

3. Define and characterize the problems in, and devise parameters for, optical and millimeter wave optical communications equipment operating in a space environment.

One of the more important objectives of the research will be determination of the effect of adverse atmospheric conditions on system bandwidth requirements and of the extent of atmospheric scattering of millimeter waves propagated parallel to the Earth's surface and marginally within the earth's atmosphere. The experiment will permit the testing of methods for locating and tracking narrow antenna beams and will allow the acquisition of data on the performance of various techniques for accomplishing this.

2. Background and Current Status

Since the aperture dimensions of high-gain antennas needed for transmission and reception are directly proportional to wave-length, it is apparent that size requirements for a communication system may be reduced when millimeter wave frequencies are used. At the same time, operation at these frequencies provides increased spectrum availability for wideband system operation.

Optical communications offer the advantages of very wide bandwidths and small physical apertures for point-to-point transmission of data in a space environment. Many variables, however, such as atmospheric attenuation and scattering, and spacecraft stabilization requirements, have yet to be established.

Data resulting from this research is paramount in planning and developing satellite systems for optical and millimeter wave space communications, optimizing the use of the total electromagnetic spectrum, and fulfilling NASA's role as space communication consultants to government and industry.

3. Description of Research

This experiment consists of two parts, a space-to-ground link and a space-to-space link. The primary distinction between them is the intervention of the earth's atmosphere. The experiments, tests, and measurements that will be made include:

1. Signal-to-noise ratio as a function of atmospheric parameters.
2. Signal-to-noise ratio as a function of receiver aperture.
3. Signal-to-noise ratio as a function of zenith angle.
4. Space background noise.
5. Laser power output as a function of both total elapsed time and operating time in the space environment.
6. The temperature and noise figure of the receiver mixer and radiation cooler, as a function of satellite orientation and time of year.
7. Round-trip, and one-way data quality compared with a reference microwave link.
8. Effects of the space environment on the laser frequency stability and bit error rate.

Atmospheric disturbances affecting the measurements include sky temperature, atmospheric turbulence, atmospheric molecular resonances, rainfall, fog, and cloud density. Experimentally induced disturbances affecting the results include pointing errors, source phase jitter, and excessive receiver noise. Differential attenuation and phase shift caused by atmospheric variations will tend to vary the time of arrival of a phase front, thus reducing signal coherency. Correlation of measured data with theory may be possible, however, since presently available theoretical analyses relate time spreading to atmospheric turbulence, inhomogeneities, and index of refraction. These theories are related to resonance phenomena in water vapor and in the oxygen molecule, as well as to gross variations in pressure and temperature.

4. Impact on Spacecraft

The major impacts of this experiment on the space vehicle are:

1. The degree of space vehicle attitude stability and control required for acquisition of the target receiver and maintenance of the communication link once it is established.
2. The availability of a viewing port unobstructed by the space vehicle's outboard equipment, and having suitable transparency over the entire spectrum of interest (visible through the far infrared).

3. Means of controlling and reducing the hazard of possible eye damage to the crew.
4. Reduction of radio-frequency interference that may be generated within the optical modulator circuits and other subsystems of the experimental equipment.

Because acquisition and pointing of the equipment are so critical to the success of this experiment, spacecraft attitude and associated rates will be required inputs to the optical tracking subsystem. Structural flexing of the spacecraft must be compensated for if attitude and rate signals are desired from the space vehicle's inertial reference system. If such compensation is not possible, the experiment tracking loop must have a self-contained reference.

5. Required Supporting Technology Development

To implement this research, high-speed, realtime amplitude, and phase correlators will be required to perform realtime analyses on the complex signal spectra that will be generated. The analyses will include auto-correlation of experimental data and cross-correlation of experimental data with locally generated spectra.

A theoretical study will be required initially to determine what techniques can be used, how they may be implemented, and how the data from the correlators can be processed and interpreted. Techniques must be developed for processing high-speed signals without the necessity of excessive data bandwidths. The output data must be of such a nature that can be directly related to communication system parameters, such as bit error rate, signal-to-noise ratios, envelope time delay, and harmonic and nonharmonic signal distortion. If proper techniques are used, complete characterization of the propagating medium should be possible.

Advancements must also be made in the areas of:

1. Tunable lasers with exceptional stability.
2. High-sensitivity low-noise detector materials and configurations.
3. Optical modulation techniques.
4. Narrowband spectra filters.

SUBDISCIPLINE SYNOPSIS

5-NS

Navigation Systems: 5-NS-1 through 5-NS-6

1. Research objectives

The objectives of this research cluster are to:

A. Evaluate advanced navigation satellite techniques. This evaluation would consist of system performance testing, e.g., establishing system accuracy as a function of user location, and satellite orbit parameters; and technology demonstrations, e.g., signal structure (coding and modulation), transmitters receivers, and antennas.

B. Evaluate the utility of onboard laser ranging techniques for measuring ranges, line-of-sight angles, and closing rate between two spacecraft and for measurement of spacecraft altitude. This includes the ability to define and characterize problems associated with the use of a laser ranger in the space environment and to determine optimal engineering parameters under various modes of operation.

C. Perform evaluation and developmental studies of space navigation devices and techniques. Included in the research are navigation systems for in-orbit navigation for earth and planetary orbiters, translunar and planetary navigation, and landing navigation for lunar or planetary missions.

D. Demonstrate the relative merits of candidate spaceborne techniques and equipments that could be used in earth orbital satellites to extend the regions of controlled air space to areas where ground surveillance is either impossible or highly problematical.

E. Aid in the definition of optimal systems approaches of air traffic control having regional and global coverages.

F. Compare the relative merits of techniques that could be used in satellites to provide time-reference signals for future collision avoidance systems.

G. Provide operational data relevant to the ELT (emergency location transmitter) uplink to the satellite.

Research will be done in the following topical areas.

- 5-NS-1 Satellite Navigation Techniques for Terrestrial Users
- 5-NS-2 Onboard Laser Ranging
- 5-NS-3 Autonomous Navigation Systems for Space
- 5-NS-4 Surveillance Systems
- 5-NS-5 Collision Avoidance System Techniques
- 5-NS-6 Search and Rescue Systems

2. Background and Current Status

The determination of position and velocity of space vehicles by means of radio location techniques and extensive ground-based computer smoothing has been successfully and extensively employed in the guidance of ballistic missiles and in control of both automated and manned spacecraft. The basic limitations in the achievable accuracy have proven to be due to the uncertainty in our knowledge of the shape of the geoid and tie-ins of geodetic reference points, such as the European and North American Datum.

The navigation requirements of high-velocity vehicles, such as Mach 2 (and higher) aircraft are more stringent than those for slower moving objects since position and velocity updates must be available in near-realtime; i.e., within a period proportional to d/V, where d represents the required position accuracy and V is the vehicle velocity. Consequently, the minutes or hours of data smoothing to achieve the required accuracy by normal means are not available and more advanced techniques of achieving near-realtime position and velocity information must be considered.

Unlike microwave radars, optical systems for a laser ranging device may be constructed to maintain a very high degree of isolation between the transmitter and the receiver, allowing either cw or pulsed operation and further allowing measurement capability to essentially zero range. Short pulses available from such devices, coupled with the extremely narrow beamwidths that may be obtained from small physical apertures, result in extremely good accuracy and resolution in both range and angle.

Gemini and Apollo flights have demonstrated that fairly simple, optically aided space navigation is feasible. However, the sensors involved would not be adequate for long-duration planetary missions, or for precise planetary reentry and landing guidance without the radio-tracking support used on the Apollo mission.

The primary experimental background in the autonomous navigation sensor performance has come from the TV experiments on the Mariner (Mars) flights, in which TV data were used to improve navigation estimates in the vicinity of the planets. TV navigation in conjunction with radio tracking is expected to be a key element in the performance of a grand-tour spacecraft. Clearly, there is very limited data on the performance of such sensors in various mission modes, and performance (or error) model development remains a key item in the research objectives.

ATC systems in current use, or under study for future use, utilizing ground-based surveillance radars against active beacons within the aircraft, suffer from many problems that would be greatly alleviated or eliminated altogether through the use of space-based surveillance.

Several collision avoidance systems have been developed, utilizing time synchronization as a critical element to their success. Most of these systems have been developed by the military services for use on military aircraft in formation flight.

Maintenance of synchronization in areas of high traffic density remain a major problem in these systems. Satellite-borne clocks could alleviate this condition by providing synchronization to a wider area from a single source.

Current search-and-rescue operations lack adequate capability in two areas:

1. The timely detection of a distress situation.
2. The timely localization of an emergency location transmitter (ELT).

Although various search-and-rescue (SAR) concepts and systems using satellites have been proposed, none have currently progressed beyond the proposal stage. Emergency location transmitter concepts being supported by the FAA are primarily suited to aural detection by aircraft pilots and are not intended for satellite detection and location techniques. One preliminary study has shown that the existing FAA ELT requirements may result in a marginally adequate signal-to-noise ratio at the satellite.

3. Description of Research

A comprehensive program, which includes simulation of system concepts, creation of and testing with the necessary ground environment (ground stations and user terminals), and development and demonstration of new technology, is required to expedite the development of components and to provide the engineering data upon which decisions to commit to a particular system development may be based. The economics of a practical navigation system require that all potential applications be considered and particularly that the needs of the small user terminal be reflected in the final system decision.

For a practical test program, it may not be possible to fully simulate all aspects of system geometry; consequently, emphasis should be placed on system modeling and the provision of statistical inputs to the error models.

Applicable areas in which a body of theoretical knowledge exists and in which data will be taken include tropospheric propagation, ionospheric propagation, multipath, search and acquisition, detection theory, theory of matched filters, and modulation theory. Relative signal levels will depend primarily upon the detection technique employed and must be adjusted to meet the requirements of the system being simulated.

4. Impact on Spacecraft

Through combinations of reconfigurable space vehicles, subsatellites, and synchronous satellites (e.g., ATS), various candidate satellite navigation system configurations can be simulated and accuracy evaluated in the presence of multipath and other propagation effects. Man's in-orbit participation in the actual tests may be minimal, since most data processing or recording could be done at user terminals. But experiments participation will involve configuration of space hardware for the tests, turning on and tuning equipment, and occasional equipment monitoring for satisfactory operation. Equipment operation could be automated, and the experiments themselves performed by automated subsatellites. The desirability of varying many of the parameters during the measurements, however, suggests that the experiments be performed in conjunction with a manned space laboratory.

5. Required Supporting Technology Development

STD requirements include development of subsatellites; improvement in satellite position determination from the orbital research facility; development of autonomous navigation sensors; and development of a laser radar. Additional discussion is contained in Appendix C.

3.7 SCREENING AND GROUPING OF CRITICAL ISSUES IN EARTH OBSERVATIONS

3.7.1 General Procedure

In the organized overview analysis of the seven subdisciplines of Earth Observations including Earth Physics, Agriculture and Forestry, Geography and Cartography, Geology, Hydrology, Oceanography, and Meteorology, 658 specific critical issues (research objectives) were defined (Figure 3-22).

These critical issues were screened for applicability to fulfillment by (1) research in space and (2) research in association with manned space platforms. After elimination of objectives that will be fulfilled by current or ongoing NASA programs, grouping by means of commonality in observation and instrumentation requirements resulted in the identification of 34 research clusters in Earth Observations for detailed consideration in this study. This was supported by study-team consultants named in Table 3-38.

The primary sources of guidance for the overview analysis in Earth Observations were (1) the scientific and technological objectives developed by the NASA Langley Research Center, and (2) program documentation developed by the NASA

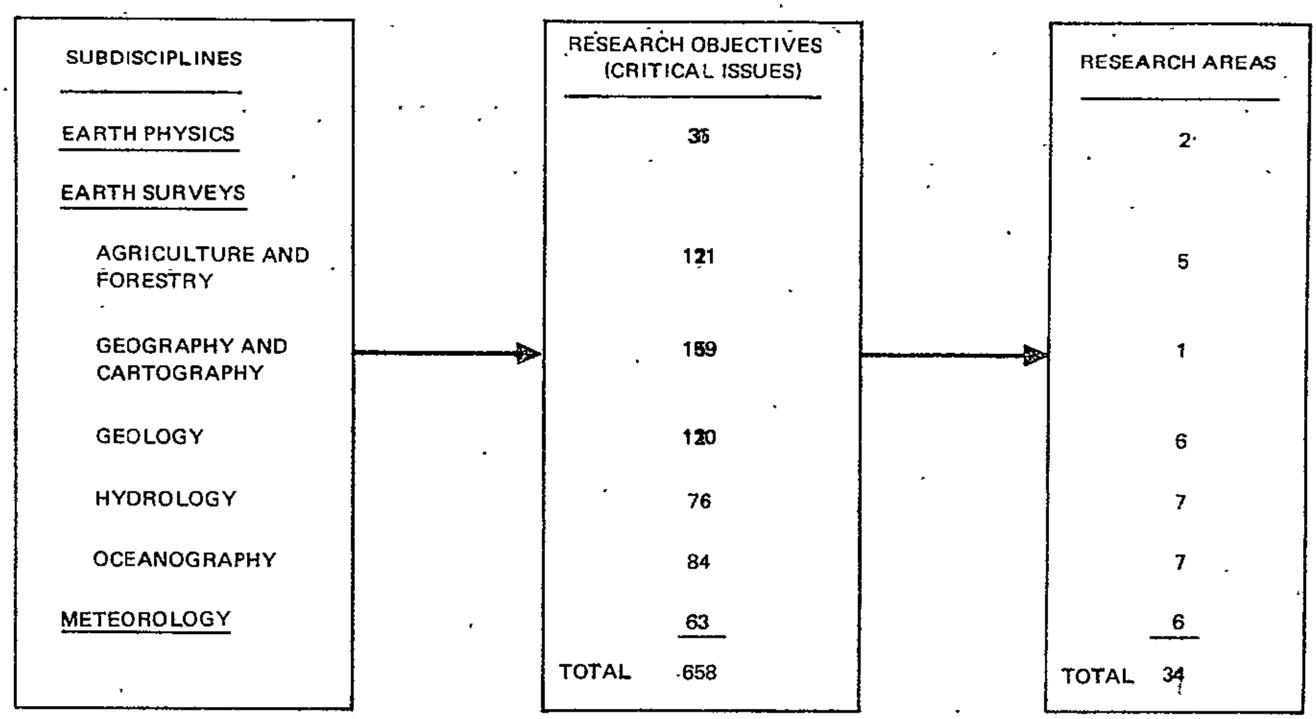

Figure 3-22. Statistical Summary of Earth Observations Analysis

TABLE 3-38

STUDY-TEAM CONSULTANTS—EARTH OBSERVATIONS

Name	Affiliation	Technical Area
Leonard W. Bowden	University of California, Riverside, California	Geography-Urban Environment Technology, MSC Aircraft Program
John A. Dracup	University of California, Los Angeles, California	Hydrology-Water Resources
William M. Kaula	University of California Los Angeles, California	Geophysics and Satellite Geodesy
Joseph Lintz	University of Nevada and the National Science Foundation, Reno, Nevada	Geology-Ground Truth Test Sites for Calibration of Remote Sensor Instruments, Land Use MSC Aircraft Program
Gene A. Thorley	University of California, Berkeley, California	Forestry and Agriculture

Earth Surveys Steering Panel (Earth Resources Subpanel) (Figure 3-23). Additional supporting data consisted of reports developed by government agencies and committees; institutional studies and symposia; and contractor studies defining the requirements of using agencies, the results of scientific research in remote sensing, the applicability of earth-orbiting satellites, and the uses of man in earth observations (References 3.7-1 through 3.7-42 found at the end of this subsection).

3.7.1.1 Identification of Critical Issues (Research Objectives) as Candidates for the Earth Orbital Experiment Program

After development of the critical issues within each of the seven subdisciplines of Earth Observations, the information and data requirements of each issue were considered in their broad aspects to classify the issues into one of the four following categories:

A. Requirements for improvements and advancements in terrestrial equipment, and facilities identified during preliminary screening. (36 issues)

B. Improvements in ground-based operational methods or techniques and development of advance concepts required. (9 issues)

C. Requirements of the critical issue covered within another discipline. (1 issue)

D. Requirements for fulfillment of the critical issue potentially accommodated by a remote measurement or sensing technique. The issue is therefore a candidate for research in space (in either automated or manned space flight). (612 issues)

Only critical issues in the last category were considered further in the study. Thus it can be seen that this preliminary screening reduced the number of critical issues considered in the Earth Observations discipline from 658 to 612.

The classifications that were assigned to individual critical issues are shown in Table 6, Appendix B, by use of appropriate symbols in the margin of each page.

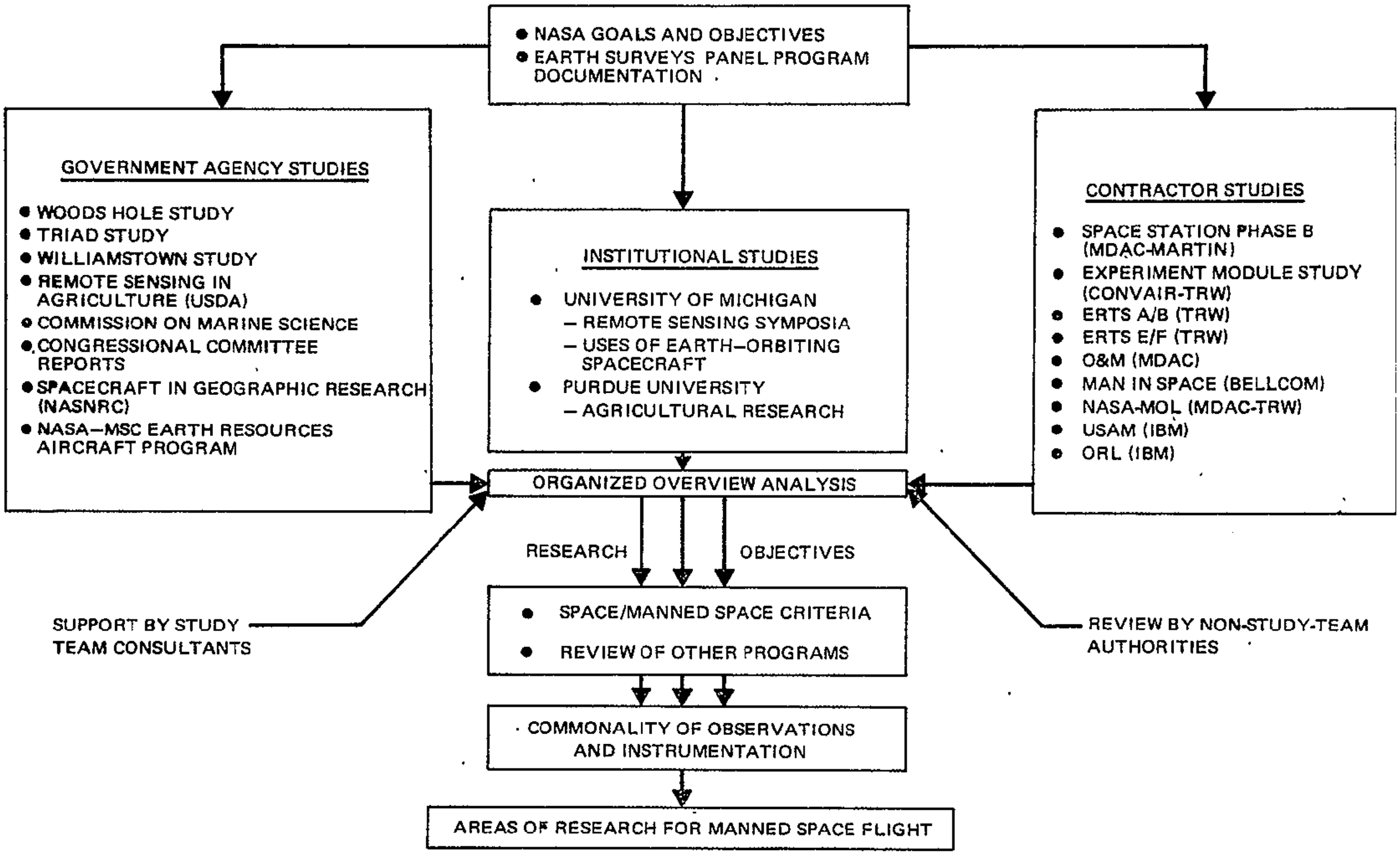

Figure 3-23. Sources of Guidance Information for Identifying Areas of Research in Earth Observations

3.7.1.2 Screening of Critical Issues for Research in Space

After the broad classification of 612 critical issues as candidates for research in space, criteria were developed to determine which of these research objectives could indeed be fulfilled by space research, using either manned or automated earth orbiting satellites. These criteria are summarized in Table 3-39. This screening process utilized seven rating terms: essential (E), helpful (H), no effect (N), tolerable (T), intolerable (I), effects unknown (U), and not applicable (NA).

The first three rating terms (E, H, and N) reflect the possible advantages of orbital characteristics by consideration of various criteria. The high altitude associated with orbiting spacecraft was found to be essential in several areas of Earth Physics (geodesy), where ground tracking of distant objects from widely spaced ground tracking stations is mandatory. To obtain synoptic data in other

TABLE 3-39

CRITERIA FOR SCREENING OF CRITICAL ISSUES APPLICABLE TO SPACEFLIGHT (MANNED OR AUTOMATED)

Orbital Characteristics	Space Environment Characteristics
• Orbital Altitudes	• Gravitational Effects
• Wide Areal/Geographic Coverage	• Atmosphere (Vacuum)
• Target Selection	• Meteoroids
• Repeatable Ground Track	• Atmospheric Attenuation
• Orbital Velocity-to-Altitude (V/H) Ratio	• Cosmic Radiation
• Relative Velocity	• Radiation Belts

Rating Terms

E = Essential
H = Helpful
N = No Effect
T = Tolerable
I = Intolerable
U = Effects Unknown
NA = Not applicable

subdisciplines, the requirement for extreme altitude was found less important than that of wide areal (geographic) coverage. Target selection was found to be helpful in obtaining data in cloud-free areas in most of the disciplines. Repetitive coverage of the same area, or a repeatable ground track, is of particular advantage where phenomena may be rapidly changing, as in flood warning or damage assessment. Orbital velocity-to-altitude (V/H) ratios (the apparent angular velocity of a fixed ground target) were found to have no effect in many cases, as the rate of apparent image motion is relatively slow and image motion compensation can be provided (i.e., in photographic missions). The criterion of relative velocity, applicable in satellite-to-satellite tracking, was generally found to have no effect or to be tolerable.

The second group of rating terms (N, T, and I) reflected the possible disadvantages of the space environment. Criteria considered were the effect of zero gravity, atmospheric vacuum, meteoroid bombardment, atmospheric attenuation, and the effects of both cosmic radiation and the radiation belts of the earth. In all of the subdisciplines, the effects of zero gravity and atmospheric vacuum were found to be of little consequence. Where optical instrumentation is used, protection from meteoroid bombardment must be provided to prevent damage of optical elements during extended periods. Atmospheric attenuation was found to be tolerable in most areas, with the exception of the subdiscipline of Meteorology, where the measurement of the vertical structure of the atmosphere and the atmospheric attenuation is a primary objective. The effect of cosmic radiation and the radiation belts of the earth must be considered in most of the subdisciplines in which photographic missions are required, as shielding of photographic film must be provided.

3.7.1.3 Screening of Critical Issues for Manned Space Research

The critical issues that were found to be suitable for fulfillment by research in space (in either manned or automated Earth orbiting satellites) were then examined for suitability to manned spaceflight, using the criteria defined in Table 3-40. Again, the evaluation utilized the same seven nonweighted ratings.

TABLE 3-40

CRITERIA FOR SCREENING OF CRITICAL ISSUES APPLICABLE TO MANNED SPACEFLIGHT

Participation of Man

Scientist-Observer

- Realtime data analysis and evaluation
- Multiple sensor use
- Sensor mode and parameter selection
- Cooperation with principal investigator on the ground

Development Engineer

- Target selection
- Sensor operation and parameter variation
- Evaluation of sensor design and performance
- Component qualification testing

Technician

- Equipment setup, checkout, maintenance, and calibration
- Servicing of sensor and equipment consumables

Flight Safety

- Environmental extremes (external) (radiation, temperature, vacuum)
- Exceeds physiological limits (weightlessness, fatigue, dehydration)
- Excessive psychological stress (sensory deprivation, etc.)
- Affects crew safety (high voltage, noise level, flammables)

Mission Performance Degradation

- Acceleration disturbances (attitude control, crew mobility)
- Effluent release (environmental contamination)
- Repetitive duty cycles (continuous high-precision observations)

Rating Terms

E = Essential
H = Helpful
N = No effect
T = Tolerable
I = Intolerable
U = Effects unknown
NA = Not applicable

Appropriate criteria were considered regarding the advantages of man participating in research in space as a scientist-observer, development engineer, or technician. As a scientist-observer, man was found to have a useful role, particularly in the case of rapid assessment of damage resulting from forest fires, flooding, earthquakes, or other catastrophic occurrences. As a development engineer, the capability of target selection was found to be of importance in selecting observables in the presence of scattered cloud cover. As a technician, the presence of man was found to be of value, particularly in deploying large structures (i.e., radar antennas) and in preliminary calibration, checkout, and setup of complex instrumentation (i.e., multispectral imaging systems using closed-cycle cryogenic cooling systems).

Flight safety was then considered from the standpoints of the effects of environmental extremes, of exceeding physiological limits, of excessive psychological stress, and of experiment requirements upon crew safety. An example of the first criterion would be an experiment that required prolonged exposure to a radiation environment. An example of the second criterion would be an experiment requiring prolonged high-precision manipulation of complex instrumentation. The third criterion would be of importance where sensory deprivation would result from performing an experiment. Finally, the fourth criterion would be considered for experiments involving such problems as high voltages, high temperatures, and excessive noise levels.

In general, it was found that the experimental requirements associated with fulfillment of the critical issues of the seven subdisciplines of Earth Observations will not affect flight safety, because the instrumentation (primarily electro-optical and radio-frequency sensors) and observation requirements will not place excessive requirements on the crew.

The third group of criteria considered the degrading effects of the presence of man on accomplishing the requirements of the mission. These included acceleration disturbances due to crew mobility, the release of effluents, and the possible requirements for continuous and repetitive use of high-precision equipment.

Only in the subdiscipline of Earth Physics were these criteria found to have intolerable effects upon experiment requirements, and the majority of critical issues in this area were found to be suitable for research using automated rather than manned earth orbiting satellites. The eventual requirements of Earth Physics require the use of satellite altimeters with a precision of 10 cm, and ground based tracking of earth orbiting satellites with a precision of 2 cm. The use of manned spacecraft is not considered practical for experiment requirements of this level of precision.

3.7.1.4 Influence of Previous and Ongoing Programs

The final screening of the critical issues in each of the subdisciplines before they were included in the earth orbital experiment program considered whether the research objectives may have been fulfilled by previous NASA (or other government agency) programs, or whether the objectives may be satisfied by the results of ongoing programs.

In the subdisciplines of Meteorology and Earth Physics (geodesy), a considerable amount of research has been accomplished in space. In the five subdisciplines under Earth Resources, research to date has been conducted primarily with instrumented aircraft.

The criteria used in rating the critical issues were:

A. Preliminary information has been or will be developed by another program.

B. Research objectives have been or will be completely satisfied by another program.

If the research objectives associated with any critical issue were judged to be less than completely satisfied by previous or ongoing programs, the critical issue was retained in the Earth orbital experiment program.

3.7.1.5 Research Clusters Selected for the Earth Orbital Experiment Program

After selection of the critical issues (or research objectives) for the earth orbital experiment program within each of the seven subdisciplines of Earth

Observations, the observation and instrumentation requirements of each were examined. It was determined that the data requirements of a number of critical issues could be satisfied by a common experiment approach. Thus a small number of related research areas (or research clusters), each including a number of critical issues within each of the seven subdisciplines, were identified as shown in Table 3-41.

3.7.2 Screening and Grouping of Critical Issues in Earth Physics

The goals of Earth Physics in the coming decade are contained in the report of the so-called "Williamstown Study" on Solid Earth and Ocean Physics and are addressed to accomplishing the following:

A. What are the long-term dynamics of the solid earth? Identify the driving forces and response mechanisms that account for the plate motions, earthquakes, variations in gravitational field, and tectonics.

B. What is the general circulation of the oceans? Account for the observed currents, temperature, and salinity; infer the necessary return flows; and furnish inputs to numerical weather prediction.

C. What is the earthquake mechanism? Improve understanding of how earthquakes occur, thus improving protection against tsunamis and earthquakes.

D. What is the nature of the global heat balance? Describe the relation between currents and heat transport, increase knowledge of air-sea interaction, and detect changes in state of a long-term global nature.

E. What is the nature of the geomagnetic dynamo? Identify the energy source and mechanisms of interaction in the core, and hence, account for the patterns of the internal magnetic field and the variation in the core-mantle coupling.

F. What is the rate and mechanism of energy dissipation in the oceans? Define the locations and mechanisms of energy dissipation, and thus explain such phenomena as damping of the Chandler wobble, the tide pattern of the ocean, and evolution of the earth-moon system.

G. What are the rotational dynamics of the earth? Explain the entire complex of excitational mechanisms, such as rheology, resonances, and damping, associated with the spectrum of variations in the rotation rate and wobbles of the rotation axis.

Of these goals, the first three and the last were expanded to develop the critical issues for Earth Physics in this study. The fourth and sixth relate mainly to Oceanography, and the fifth uses data taken primarily in the areas

TABLE 3-41 (page 1 of 4)

RESEARCH CLUSTERS IN EARTH OBSERVATIONS

Subdiscipline	Research Cluster		Application
Earth Physics	6-EP-1	Photographic Coverage of the Earth	Obtaining photographic coverage of the Earth with a resolution of 500 m
	6-EP-2	Identification of Volcanic Activity	Location of sources of infrared activity on the surface of the Earth
Agriculture, Forest and, Range Resources	6-A/F-1	Crop Inventory and Land Use	Location and acreage of cultivated, forested, and ranged lands
	6-A/F-2	Soil Type Mapping	Location of agricultural soil types and their fertility
	6-A/F-3	Crop Identification	Identification of principal crop, forest, and range land species
	6-A/F-4	Crop Vigor and Yield Prediction	Prediction of vigor and yield of cultivated food and fiber crops
	6-A/F-5	Wildfire Detection and Mapping	Detection and tracking of fires in forest, range, and wild lands
Geography and Cartography	6-G/C-1	Photographic and Multisensor Mapping	Regional planning studies
			Relationships between man and environment
			Resource Utilization
			Population dynamics
			Transportation phenomena
			Mapping

TABLE 3-41 (page 2 of 4)

Subdiscipline	Research Cluster		Application
Geology and Mineral Resources	6-G-1	Rock and Soil Type Identification	Engineering site selection, location, construction materials, food and fibre production, trafficability of terrain
	6-G-2	Use of Earth's Crust to Store and Condition Commodities or Waste	Storage of water; storage and conditioning of insecticides, detergents, synthetic products, and radioactive waste
	6-G-3	Geologic Disaster Avoidance	Warning of volcanic activity, earthquakes, massive erosion (dust bowls), landslides, sand dune encroachment, reservoir sedimentation
	6-G-4	Utilization of Geothermal Energy Sources	Location of areas with potential for use in low-cost generation of power or as a heat source
	6-G-5	Mineral and Oil Deposit Discovery	Location of potentially valuable sources of ores, minerals, coal, oil, and natural gas
	6-G-6	Identification of Land Forms and Structural Forms	Relating of land forms to dynamic processes and identification of structural forms from associated vegetation
Hydrology and Water Resources	6-H-1	Determination of Pollution in Water Resources	Control of the pollution of the water resources of the United States
	6-H-2	Flood Warning and Damage Assessment	Rapid collection of synoptic data for flood warning and damage assessment
	6-H-3	Synoptic Inventory of Major Lakes and Reservoirs	Surface water inventory to permit better utilization of water resources
	6-H-4	Synoptic Inventory of Snow and Ice	Increased understanding of the hydrologic cycle and better resource utilization

TABLE 3-41 (page 3 of 4)

Subdiscipline	Research Cluster		Application
Hydrology and Water Resources	6-H-5	Survey of Soil Moisture in Selected Areas of the North American Continent	Agricultural and hydrologic applications, engineering site selection, hydrologic cycle data
	6-H-6	Location of Underground Water Sources in Selected Areas	Location of new sources of fresh water
	6-H-7	Survey of Hydrologic Features of Major River Basins	Regional water management
Oceanography and Marine Resources	6-O-1	Ocean Pollution Identification, Measurement and Effects	Pollution control and abatement
	6-O-2	Solar Energy Partition and Heating in the Sea Surface Layer	Sea surface temperature and fish catch forecasts
	6-O-3	Ocean Population Dynamics and Fishery Resources	Fishery resource management
	6-O-4	Ocean Current and Tide Forecasting	Sea and swell, and marine shipping
	6-O-5	Ocean Physical Properties	Mathematical model improvement
	6-O-6	Ocean Solid Boundary Processes	Beach erosion control
	6-O-7	Ocean Surface Activity Forecasting	Ship routing

TABLE 3-41 (page 4 of 4)

Subdiscipline		Research Cluster	Application
Meteorology	6-M-1	Determination of Boundary Layer Exchange Processes Using IR Radiometry	Exchange of momentum, heat, and moisture at terrain-atmosphere interface and lowest atmospheric layer
	6-M-2	UHF Sferics Detection	Study of convective and electrical activity in severe storms
	6-M-3	Atmosphere Density Measurements by Stellar Occultation	Measurement of spatial and temporal distribution of atmospheric density
	6-M-4	Zero-G Environment Cloud Physics Experiment	Obtaining understanding of cloud dynamics
	6-M-5	Detection and Monitoring of Atmospheric Pollutants	Monitoring of global distribution of atmospheric contaminants
	6-M-6	Support of Studies of Special Geographical Areas	Support of GARP and other programs (i.e., arctic heat budget study)

of Space Physics and Geology. The critical issues in the first two groups relate to the traditional area of geodesy, which treats the gravitational and geometric state of the earth in land and ocean areas. The critical issues in the third and in the last categories (earthquake mechanism and rotational dynamics), relate to the earth's changes of state. The critical issues in Earth Physics are contained in Table 6, Appendix B.

3.7.2.1 Screening for Space-Research Applicability
Critical issues in the Earth Physics subdiscipline were screened for a space-research applicability according to the general procedure described in Subsection 3.7.1.2. The results are summarized in Table 3-42. The rationale for these decisions is described below.

Because the data on the earth's shape and gravitational field have been limited to surface measurement of accessible land areas and a few limited ocean areas, the primary asset of space is the possibility of having complete coverage of the earth's surface with uniformly accurate data. Up to the present time, even space coverage has been limited by the location of earth-based trackers. The high-frequency terms in the gravitational field have been lost in the averaging effects while a low-altitude satellite is out of view of the tracker. Drag effects have limited the use of low-altitude satellites in determining the earth's gravitational potential. Geometric links made by satellite lie mainly between well-surveyed continental areas and islands housing tracking facilities.

With the advent of the concepts for satellite-to-satellite tracking, the radar altimeter, and the drag-free low-altitude satellite, the possibility of complete global geometric and gravimetric data is at hand. Increasing accuracies in the methods of satellite geodesy now allow the extension of objectives in Earth Physics to solving the ocean circulation problem. By combining the ability to obtain the geometric position of the mean sea surface by radar altimetry with the ability to obtain high-frequency terms in the gravitational potential by drag-free satellites at low altitudes, it is possible to measure the separations between the mean sea surface and the geoid (equipotential) surface to accuracies presently of 1 m and eventually of 10 cm. It is desirable to combine satellite-

Table 3-42

CRITICAL ISSUES IN EARTH PHYSICS CATEGORIZED FOR SPACE AND FOR MANNED SPACEFLIGHT

	Application Area	Critical Issue Number	Critical Issue Research Objective	Suitable for Space	Suitable for Manned Space Experiments	Not Satisfied by Ongoing Program	Candidate for Manned Space Flight
Solid Earth Dynamics	Geometric Description of Earth's Surface	6.1.1.1.1.1	Define local datums on UWD** to 10 meters	√	R-A*		
		6.1.1.1.1.2	Locate tracking stations on UWD to ±5 meters	√	R-A		
		6.1.1.1.1.3	Position DSN*** stations to 1 meter	√	R-A		
		6.1.1.1.1.4	Relative positions of 3 tectonic plates to ±15 cm	√	R-C		
		6.1.1.1.1.5	Relative positions of points in large tectonic plates, to ±2 cm	√	R-C		
		6.1.1.1.1.6	Photographic coverage of Earth to ±500 meters	√	√	√	√√
		6.1.1.1.1.7	Positions of ground beacons to ±1 m	√	R-C		
	Gravitational Potential	6.1.1.1.2.1	Earth model harmonic terms (1/2 wave) to 400 km (Solid Earth)	√	R-B		
		6.1.1.1.2.2	Earth model harmonic terms (1/2 wave) to 100 km (Solid Earth)	√	R-B		
Ocean Circulation	Geopotential Field	6.1.1.2.1.1	Earth model harmonic terms (1/2 wave) to 250 km (Oceans)	√	R-B		
		6.1.1.2.1.2	Earth model harmonic terms (1/2 wave) to 100 km (Oceans)	√	R-B		
		6.1.1.2.1.3	Improvements needed in geopotential theory	√	R-B		
		6.1.1.2.1.4	Gravimetric measurements to support 10-cm requirements in radar altimeters	√	R-B		
	Ocean Height Above Geoid	6.1.1.2.2.1	Variations of mean ocean surface to ±1 meters	√	R-B		
		6.1.1.2.2.2	Variations of mean ocean surface to ±10 cm	√	R-C		
		6.1.1.2.2.3	Model for mean ocean surface				
	Navigation Requirements	6.1.1.2.3.1	Locate ships on UWD to ±100 meters	√	R-D		
		6.1.1.2.3.2	Locate floats on UWD to ±2 km	√	R-D		
Earthquake Activity	Seismic Fault Motions	6.1.2.1.1.1	Position changes along fault zones by laser tracking to ±15 cm	√	√	√	√√
		6.1.2.1.1.2	Position changes along fault zones to ±2 cm				
	Tectonic Plate Motions	6.1.2.1.2.1	Position changes to ±15 cm (tectonic plates)				
		6.1.2.1.2.2	Position changes to ±2 cm (tectonic plates)				
	Volcanic Activity	6.1.2.1.3.1	Locate infrared sources of activity	√	√	√	√√
Global Heat Balance		6.1.2.2.1	Global heat balance within Earth's crust	√	√	√	√√
Ocean Energy Dissipation		6.1.2.4.1	Energy dissipation mechanisms of the oceans	√	√	√	√√
Earth Rotation	Coordinate System Definition	6.1.2.5.1.1	Locate laser tracking sites to ±15 cm	√	R-C		
		6.1.2.5.1.2	Locate VLBI sites to ±15 cm	√	R-C		
		6.1.2.5.1.3	Relative positions of laser and VLBI sites to ±2 cm	√	R-C		
	Polar Motion	6.1.2.5.2.1	Precise location of the pole	√	R-C		
		6.1.2.5.2.2	Location of pole to 3 to 20 cm	√	R-C		
	Earth Rotation	6.1.2.5.3.1	Precision time duration of the day	√	R-C		
		6.1.2.5.3.2	Length of day to ±1 msec	√	R-C		
	Inertial Direction Finding	6.1.2.5.4.1	Radio source direction to ±0.005 arc-sec	√	R-C		
		6.1.2.5.4.2	Direction of radio sources to ±0.001 arc-sec	√	R-C		

*Rejected for reason A, B, C, or D as discussed in Subsection 3.7.2.2.
**Unified Word Datum
***Deep Space Network

FOLDOUT FRAME

FOLDOUT FRAME 2

to-satellite tracking with both the drag-free satellite system and the radar altimeter system. Although differing altitude requirements may cause the drag-free system to be launched separately from the altimeter system, both require tracking accuracies obtainable from a high satellite. The tracker satellite coordinates are well known relative to the geocenter. Tracking from ground stations suffers from atmospheric effects and station location errors. The high-altitude satellites in stable orbits could be carefully located with laser trackers and would provide broad tracking coverage of the near-surface vehicles carrying the drag-free experiment and the radar altimeter.

Without the very accurate tracking capability associated with the satellite-to-satellite tracking system, use of neither the drag-free system to obtain an accurate geopotential model to 500-km wavelengths nor the radar altimeter for modeling the ocean surface to 1 m could provide useful data. Both require extremely accurate spacecraft position and velocity information to interpret the experimental data.

Another promising technique for Earth Physics is laser ranging to the moon or to a distant artificial satellite. The laser-ranging system is one of two techniques that show promise of measuring changes in the earth to a centimeter-per-year resolution to verify the inferences of the plate-tectonic theory and to monitor the polar wobble and rotation more accurately. The initial system should include stations in the stable portions of at least three of the major geologic plates: for example, Hawaii, Australia, and the Canadian shield. The number of additional stations that could be effectively employed at the stated accuracy level is related to the likely number of tectonic plates, which is now estimated to be 20 or more. Supplemental supporting research required for the laser-ranging system is that of selecting the optimum satellite. The moon may introduce too many irregularities of its own; a geosynchronous satellite may have errors that would invalidate measurements of the longer periodic motion of the pole. The ongoing program of laser tracking of close satellites by the Smithsonian Astrophysical Observatory and other agencies should be carried out to develop techniques and organizational capability toward the above-stated system.

A competitive technique to laser ranging is very-long-baseline interferometry (VLBI). About the same considerations apply to the siting of VLBI antennas as to the laser ranging. Ideally, the two systems are complementary, since they use different parts of the electromagnetic spectrum and observe different components of position. Laser ranging has the advantage of being less susceptible to tropospheric refraction, and VLBI has the advantage of being able to make observations during cloudy weather and to reference to an inertial coordinate system. The increased confidence in results obtained by the combined systems would be well worth the extra expense. Supplemental research exploiting the data generated by both laser ranging and VLBI should include observations to determine deformation and rupture along fault zones, as well as around the ranging and VLBI sites; theory and data analysis of the earthquake mechanism, including its effect on the Chandler wobble; investigation of core-mantle coupling and of the geomagnetic dynamo; definition of, and relations between, fundamental reference systems; and connection of the laser or VLBI to conventional geodetic control (satellite as well as terrestrial).

Low-altitude satellites with extremely accurate and continuous tracking coverage are necessary for achieving the goals of Earth Physics. Present technology will allow low-altitude (250-km) drag-free satellites with 2-year lifetimes for geodetic applications. The capability entails a low-thrust compensation of drag effects determined by following a free-floating ball internal to the satellite. Continuous range-rate tracking to an accuracy of 1 mm/sec for 10-sec smoothing periods is possible for high-to-low satellite tracking and will allow breakthroughs to higher-frequency terms in the gravitational potential. Radar altimeters at sea will currently allow the location of the mean sea surface relative to the satellite to 1 m, and eventually to 10 cm.

Critical issues that can be resolved better with ground-based experiments were rejected. In Earth Physics, some critical issues may be treated by a combination of earth-based and satellite-based experiments. In the case of laser tracking and very-long-baseline radio interferometry, the major portion of the experiment is ground-based. Because the corner reflectors, radio transmitters, and sometimes even one antenna in the VLBI pair, are satellite- or moon-based, the critical issues answered by these experiments were retained.

Both land survey and land and ocean gravimetry data will be combined with satellite data in improving the Unified World Datum.

All but four critical issues have been retained as meeting the space research applicability requirements, as shown in Table 3-42, although many are resolved in part by ground-based experiments.

3.7.2.2 Screening for Manned Space Research Applicability

The vast majority of experiments in Earth Physics are best performed in unmanned spacecraft. Because the data desired are exact determinations of positions and accelerations, the presence of man, with the accompanying attitude maneuvers (which produce small uncompensated accelerations) and effluent releases, is inconsistent with the goals of Earth Physics.

Some of the specific reasons for rejection of critical issues with respect to manned spacecraft, which are applied in Table 3-42, are as follows:

A. Because effluent release and attitude maneuvers produce disturbances, all experiments requiring accurate (1-mm/sec range rate) satellite-to-satellite tracking were rejected.

B. The drag-free experiment (which requires the satellite to follow an internal free-floating ball and which operates at an altitude of 250 km or less) is inconsistent with the manned platform. Torques on the satellite shell would confuse the sensitive tracking device, and the fuel requirements for an entire platform to track the free-floating ball would be enormous.

C. The very-long-baseline interferometry experiment and the laser tracking experiment require high-altitude (nearly synchronous) satellites or the moon for placement of radio transmitters and reflectors. The manned space station fails to satisfy this requirement.

D. Satellites designed to fulfill navigation requirements (the locations of ships and buoys) should be at high (nearly synchronous) altitudes to obtain frequent and complete coverage of the ocean surfaces.

In the critical issues related to world photographic coverage to 500-m resolution or better (Item 6.1.1.1.1.6, Table 3-42) and in detection of volcanic activity on land or at sea (Item 6.1.2.1.3.1) the beneficial attributes of a manned space station can be used to advantage. Because the astronaut can visually monitor cloud conditions and spot unusual activity of a volcanic sort at sea, these critical issues are best treated on a manned space platform.

Three other critical issues were also identified with manned space platforms, as may be seen in Table 3-42. These issues, however, as may be seen in Table 6, Appendix B, were subsequently clustered with critical issues from other subdisciplines of Earth Observations. This method of grouping critical issues promotes commonality in observational techniques.

3.7.2.3 Contributions of Ongoing Programs

The critical issues in Earth Physics that are satisfied by ongoing programs have already been eliminated by the manned space screening described in Subsection 3.7.2.2.

None of the five critical issues remaining after the screening for manned space platform applicability were found to be satisfied by ongoing programs. Therefore, all were included in research clusters. Photographic coverage of the earth to 500-m resolution (Item 6.1.1.1.1.6) is treated solely by research cluster 6-EP-1 Table (3-41). Location of incipient volcanic activity (Item 6.1.2.1.3.1) is treated in part by research cluster 6-EP-2 and in part by cluster 6-G-3. The other three critical issues retained are addressed only by research clusters in other subdisciplines of Earth Observations.

3.7.2.4 Brief Description of the Research Clusters

In summary, in the subdiscipline of Earth Physics, two research clusters (Table 3-41) were formed from the five critical issues judged to be suitable for a manned earth-orbital research program. A brief description of these research clusters is presented at the end of Subsection 3.7. More detailed descriptions may be found in Appendix C.

3.7.3 Screening and Grouping of Critical Issues in Agriculture, Forest, and Range Resources

A total of 121 critical issues (Table 6, Appendix B) were developed during the preparation of the organized overview (Charts 6-5 through 6-8, Appendix A) for Agriculture, Forest, and Range Resources. Six of these critical issues were judged to be sufficiently dependent upon advanced experimental concepts that they would not be candidates for space research in the next decade. Of the remaining 115, it was not necessary to consider each one individually, since many relied on the same raw data for their solution. Consequently, these 115 critical issues were assembled into 47 pre-screening groups. The critical issues included in each of these groups are listed in Table 3-43.

The Bureau of Land Management, a USDA agency directly interested in grazing and browsing lands, might use data collected under Pre-Screening Group No. 1 to construct thematic maps such as the textbook example shown in Figure 3-24. The Economic Research Service, on the other hand, might process these data into historical statistics for economic studies of land use. Both agencies can use the same raw data, although the form of the final product and the use to which it is put will differ. The screening of the 47 pre-screening groups of critical issues for space research applicability, manned research applicability, and the influence of ongoing programs is summarized in Table 3-44.

3.7.3.1 Screening for Space-Research Applicability

There are no space-research criteria in the Agriculture, Forest, and Range Resources discipline that are different from those discussed in Subsection 3.7.1.2. They are summarized in Table 3-39.

Rationale for Retention or Rejection of Critical Issues

The criteria of orbital altitudes and width of areal coverage were evaluated together. Of the two, areal coverage is nearly always essential because agriculture, forest, range, and wild land resources are located throughout the world, and wide geographic coverage is needed to make an area-wide survey of the state of these resources. Orbital altitudes are required only because large-area coverage at high speed is practicable only above the atmosphere where there is negligible aerodynamic drag.

TABLE 3-43 (page 1 of 4)

PRE-SCREENING GROUPS OF CRITICAL ISSUES – AGRICULTURE, FORESTRY, AND RANGE RESOURCES

Research Area	Pre-Screening Group	Critical Issue Number	Critical Issue
Crop Inventory and Land Use	1. Location and acreage of food, fiber, wood, and livestock	6.2.1.1.1.3	What is the location and acreage of commercial timber forests?
	2. Location and acreage of harvested, fallow, or soil-bank land	6.2.1.1.1.6	What is the location and acreage of fallow or soil improvement land?
		6.2.1.1.1.7	What is the location and acreage of harvested crop and forest land?
		6.2.1.1.3.6	What is the location and extent of soil types?
	3. Location and acreage of grazing, browsing, and wild lands	6.2.1.1.1.2	What is the location and acreage of grazing and browsing land?
		6.2.1.1.1.9	What is the location and acreage of forest land that is pastured?
	4. Replication of past aircraft and ground experiments	6.2.1.1.1.1	What is the location and acreage of food and fiber crops?
		6.2.1.1.2.1	What are the species of food crops and fiber crops?
	5. Species and amount of food, fiber, wood, and livestock crops	6.2.1.1.2.2	What are the species of trees?
	6. Species and palatability of forage, weeds, and phreatophytes on grazing and browsing lands	6.2.1.1.1.8	What is the location and acreage of noxious weed infested land?
		6.2.1.1.2.3	What is the palatability of forage on grazing and browsing lands?
		6.2.1.1.2.6	What is the species of weeds and phreatophytes?
Yield Forecast	7. Basic sensor and signature research that is needed	6.2.1.2.1.1	What basic sensor and signature research should be done?
		6.2.1.2.2.2	What is the signature of livestock and wild life?
		6.2.1.2.2.3	What is the signature of the unique ecological systems?
		6.2.1.2.3.7	What are the seasonal changes in snow packs and glaciers?
	8. Changes in acreage of cultivated, forest, and wild lands	6.2.1.2.1.2	What are the changes in acreage of cultivated, forest and wild lands?
		6.2.1.2.2.4	What is the yield forecasts for major food, fiber and forage crops?
	9. Changes in numbers and distribution of livestock and wild life	6.2.1.2.1.3	What are the changes in numbers and distribution of livestock?
	10. Age of orchards, vineyards, and forests	6.2.1.1.2.11	What is the age of orchards, vineyards and forests?
Crop and Range Vigor	11. Signatures of diseased or infested vegetation	6.2.1.2.2.1	What is the signature of the species of food, fiber and wood crops?
	12. Location and cause of major crop failure	6.2.1.2.2.6	Where are crops, forests or range under stress?
		6.2.1.2.2.8	What is the location and extent of insect or disease infestation?
	13. Location, type, and extent of insect infestations of crops or soil	6.2.1.1.2.7	What is the location, type and extent of insect infestation of vegetation?
		6.2.1.1.2.9	What is the location, type and numbers of insects in the soil?
	14. Location, type, and extent of diseases of crops or soil	6.2.1.1.2.8	What is the location, type and extent of disease?
		6.2.1.1.2.10	What is the location, type and amount of organisms in the soil?

TABLE 3-43 (page 2 of 4)

Research Area	Pre-Screening Group	Critical Issue Number	Critical Issue
Environmental Conditions	15. Fertility, salinity, and moisture content of soil	6.2.1.1.3.1	What is the fertility of the soil?
		6.2.1.1.3.2	What is the salinity of the soil?
		6.2.1.1.3.3	What is the moisture content, porosity and permeability of the soil?
		6.2.1.2.3.4	What is the location and amount of ground water?
		6.2.1.2.3.5	What are the nutrient deficiencies of the soil?
		6.2.1.2.3.6	What are the organism deficiencies of the soil?
		6.2.1.2.3.7	What are the seasonal changes in snow packs and glaciers?
		6.2.1.2.3.8	Where are fertilizers being used?
	16. Incursion of brackish water into surface and ground water	6.2.1.1.3.5	What is the incursion of brackish water in ground and surface water?
	17. Sources and distribution mechanisms of pollution	6.2.1.2.3.2	What are the sources of pollution?
		6.2.1.2.3.3	What are the distribution mechanisms of pollution?
	18. Location and extent of erosion, siltation, and pollution	6.2.1.2.1.6	What is the location and extent of erosion, siltation and pollution?
Improved Production and Distribution	19. Location and acreage of potential arable, forest, or range lands	6.2.1.3.1.1	What is the location and acreage of potentially arable land?
		6.2.1.3.1.9	Which countries have undeveloped forest and rangeland resources?
		6.2.1.3.1.10	Where is better conversion of forage into meat products needed?
	20. Need for improved land management or conservation	6.2.1.3.1.2	Where should intensive land management be applied or improved?
		6.2.1.3.1.5	Where should more land be converted to cultivation?
		6.2.1.3.1.7	Where should conservation practices be improved?
		6.2.3.1.2.2	Where should intensive land management be applied?
		6.2.3.1.2.3	Where should land be entered or removed from cultivation?
		6.2.3.1.2.4	Where is better conversion of forage into meat products needed?
		6.2.3.2.3.4	Where is noncompliance with land management practices occurring?
		6.2.3.2.3.5	Where should conservation practices be improved?
	21. Need for better timber cutting and logging methods	6.2.1.3.1.3	Where should better timber cutting and logging methods be used?
	22. Need for forest fire detection and fighting methods	6.2.1.3.1.4	Where should forest fire detection and fighting methods be improved?
	23. Need for pesticides or fertilizers	6.2.1.1.3.4	What is the organic material content of the soil?
		6.2.1.3.1.6	Where should pesticides be used?
	24. Location and type of transportation routes	6.2.1.3.2.1	What are the location and type of transportation routes?
	25. Potential access routes to resources that are difficult to reach	6.2.1.3.2.2	What are the potential access routes to resources difficult to reach?
	26. Where and by whom are the food and timber resources consumed?	6.2.1.3.2.3	Where and by whom are the food and timber resources consumed?
		6.2.3.1.2.1	Where will data on supply and demand improve market efficiency?
		6.2.3.1.3.4	What is the economic worth of the knowledge?

TABLE 3-43 (page 3 of 4)

Research Area	Pre-Screening Group	Critical Issue Number	Critical Issue
Improved Production and Distribution (cont'd)	27. What is the weather and climate along distribution routes?	6.2.1.3.2.4 6.2.1.3.2.5	What is the weather along distribution routes? What is the climate of distribution areas?
Disaster Relief Management	28. Location, type, and extent of storm damage	6.2.1.1.1.10	What is the location, type and extent of storm damage?
	29. Location of salvageable timber or food crops	6.2.3.1.2.6 6.2.3.1.3.2	What are the market implications of storm, drought and disease? Where can damaged timber or grain be salvaged?
	30. Flammability index of forest and range	6.2.1.1.2.12	What is the flammability index of forest and range lands?
	31. Location, direction, and rate of movement of forest fires	6.2.1.1.1.11	What is the location, direction and rate of movement of forest fires?
	32. Location of major crop failures	6.2.1.2.2.7	What is the location and cause of major crop failure?
Data Collection and Analysis and Resource Modeling	33. New instrumentation and measurement techniques needed	6.2.2.1.1 6.2.2.1.2 6.2.2.2.2	What new instrumentation and measurement techniques are needed? What is the better form of data collection—statistics or maps? What is the better form of data presentation—statistics or maps?
	34. Ability of astronaut-scientist or experimenter to recognize and track a resource	6.2.2.1.5 6.2.2.1.6 6.2.2.2.7	How effectively can an astronaut recognize and track a resource? How effectively can an astronaut work with a PI on the ground? What is the value of observation and comment by the orbital crewman?
	35. Assembly of large structures, such as antennas, in space	6.2.2.1.7	Can large structures, e.g., antennas, be erected in space?
	36. Modification, calibration, repair, and maintenance of sensors in space	6.2.2.1.8 6.2.2.1.9	Can man calibrate, repair and maintain sensors in space? What sensor modification can and should be done in space?
	37. Models needed and input data required	6.2.2.1.3 6.2.2.1.4 6.2.2.2.1 6.2.2.2.3 6.2.2.2.4 6.2.2.2.8 6.2.2.3.1 6.2.2.3.2 6.2.2.3.3 6.2.2.3.4 6.2.2.3.5 6.2.2.3.6 6.2.2.3.7	What is the best size sampling unit for area classification? What is the effect of cloud obscuration? What models are needed and what should be their inputs? What is the degree of usefulness of data that has marginal resolution? What is the cost of data collected from space vs air and ground? What environmental factors affect the interpretation of sensor data? What is the effect of cloud obscuration? What is the effect of illumination intensity and angle? What is the effect of season? What is the effect of orbit altitude and slant range? What is the effect of orbit inclination? What coordination with ground truth sites and aircraft is needed? Can resources usually clouded over be observed through breaks?

TABLE 3-43 (page 4 of 4)

Research Area	Pre-Screening Group	Critical Issue Number	Critical Issue
Data Collection and Analysis and Resource Modeling	38. Man's capability for selection, evaluation, and analysis of data in space	6.2.2.2.5	How can man's capabilities combine real time analysis decision making?
		6.2.2.2.6	How much data reduction should be done in space?
National and International Uses of Data	39. Ownership of specific forest, range, and wild lands	6.2.3.1.1.3	Which countries have undeveloped agricultural, forest, or range resources?
		6.2.3.1.3.1	Where can tax revenue from resources be increased?
		6.2.3.1.3.3	What is the ownership of specific forest, range and wild lands?
	40. Condition and economic value of the grain or wood in a stand	6.2.1.2.1.5	What is the potential in board feet of timber lands?
		6.2.1.2.2.5	What is the state of vigor of crops, forests and range?
		6.2.3.1.3.5	What is the condition and value of the grain or wood in a stand?
	41. Ecological effects of dams and irrigation projects	6.2.3.1.1.4	Where are new large dams or irrigation projects needed?
		6.2.3.1.2.5	Where are dams or irrigation projects needed?
		6.2.3.2.2.4	What are the ecological effects of dams and irrigation projects?
	42. Occurrence of soil exhaustion or overgrazing	6.2.3.1.3.6	Where is soil exhaustion or overgrazing occurring?
	43. Recreation potentialities of forest, water, and wild areas	6.2.3.2.2.1	What are the recreation potentialities of forest, water and wild areas?
	44. Location of future urban expansion into rural areas	6.2.3.2.2.3	Where should new cities be placed?
		6.2.3.2.3.1	Where will future expansion of urban into rural areas occur?
		6.2.3.2.3.3	Where is regional development planning needed?
	45. Where should green belts or wilderness areas be established?	6.2.3.2.1.4	Where should migratory wild life sanctuaries be established?
		6.2.3.2.2.2	Where should green belts or wilderness areas be established?
		6.2.3.2.2.6	Where should wild life sanctuaries and game preserves be established?
		6.2.3.2.3.2	Where is pollutant emission in excess of standards?
	46. Pollution or overuse endangering the recreational use of water or forest areas	6.2.3.2.2.5	Where is pollution endangering the use of water or forest areas?
	47. What international cooperation in data acquisition and application is needed?	6.2.3.1.1.1	Which countries are importing/exporting food or fiber?
		6.2.3.1.1.2	Which countries could be combined into common markets?
		6.2.3.2.1.1	What are the natural food production and consumption areas?
		6.2.3.2.1.2	What information or training is needed by developing countries?
		6.2.3.2.1.3	What international cooperation is needed in data acquisition and use?

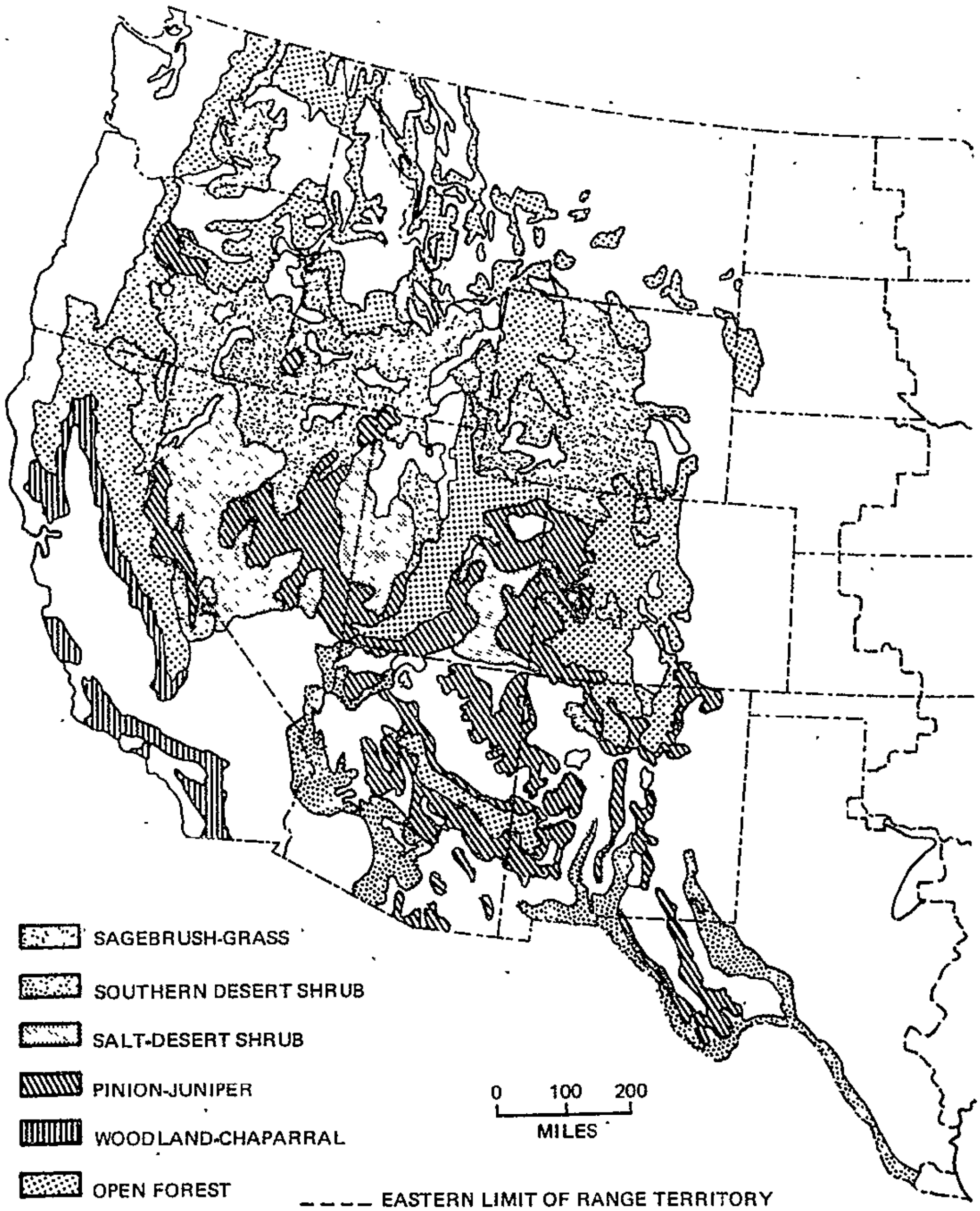

Figure 3-24. Map of Major Range Types in Western United States

Table 3-44

SCREENING OF CRITICAL ISSUES IN AGRICULTURE AND FORESTRY

* PROGRAM KEYS
  - A - ERTS A AND B
  - B - NATIONAL OPERATIONAL METEOROLOGICAL SATELLITE SYSTEM
  - C - NASA - MSC AIRCRAFT PROGRAM
  - D - MANNED MISSIONS GEMINI, APOLLO

DEFINITION OF SYMBOLS:
- E = ESSENTIAL
- H = HELPFUL
- N = NO EFFECT
- T = TOLERABLE
- I = INTOLERABLE
- U = EFFECTS UNKNOWN
- NA = NOT APPLICABLE

		PRE-SCREENING GROUP OF CRITICAL ISSUES (FROM TABLE 3-44)	SPACE RESEARCH SELECTION CRITERIA: ORBITAL CHARACTERISTICS						SPACE ENVIRONMENT CHARACTERISTICS							MANNED SPACE RESEARCH SELECTION CRITERIA: PARTICIPATION OF MAN: SCIENTIST/OBSERVER				DEVELOPMENT ENGINEER				TECHNICIAN		FLIGHT SAFETY				MISSION PERFORMANCE DEGRADATION				RELATIONSHIP TO OTHER PROGRAMS			
			ORBITAL ALTITUDES	WIDE AREAL (GEOGRAPHIC) COVERAGE	TARGET SELECTION	REPEATABLE GROUND TRACK	ORBITAL VELOCITY/ALTITUDE (V/H) RATIO	RELATIVE VELOCITY	GRAVITATIONAL EFFECTS	ATMOSPHERE (VACUUM)	METEOROIDS	ATMOSPHERIC ATTENUATION	COSMIC RADIATION	RADIATION BELTS	CRITICAL ISSUE IS SUITABLE FOR SPACE RESEARCH (√)	REAL TIME DATA ANALYSIS AND EVALUATION	MULTIPLE SENSOR USE	SENSOR MODE AND PARAMETER SELECTION	COORDINATION WITH PRINCIPAL INVESTIGATOR ON THE GROUND	TARGET SELECTION	SENSOR OPERATION AND PARAMETER VARIATION	EVALUATION OF SENSOR DESIGN AND PERFORMANCE	COMPONENT QUALIFICATION TESTING	EQUIPMENT SETUP, CHECKOUT, MAINTENANCE, AND CALIBRATION	SERVICING OF SENSOR AND EQUIPMENT CONSUMABLES	EXTERNAL ENVIRONMENTAL EXTREMES (RADIATION, TEMPERATURE, VACUUM, ETC)	EXCEEDS PHYSIOLOGICAL LIMITS (WEIGHTLESSNESS, FATIGUE, DEHYDRATION, ETC)	EXCESSIVE PSYCHOLOGICAL STRESS (SENSORY DEPRIVATION, ETC)	AFFECTS CREW SAFETY (HIGH VOLTAGE, NOISE LEVEL, INFLAMMABLES, ETC)	ACCELERATION DISTURBANCES (ATTITUDE CONTROL, CREW MOBILITY, ETC)	EFFLUENT RELEASE (ENVIRONMENTAL CONTAMINATION)	HABITABILITY (INTERIOR) REQUIREMENTS (HIGH PURITY OBSERVATIONS)	CRITICAL ISSUE IS SUITABLE FOR MANNED SPACE RESEARCH (√)	PROGRAM ON WHICH PRELIMINARY INFORMATION HAS BEEN DEVELOPED	PROGRAM COMPLETELY SATISFYING EXPERIMENT REQUIREMENTS	RESEARCH REQUIREMENTS NOT SATISFIED BY OTHER PROGRAMS (√)	CRITICAL ISSUE IS CANDIDATE FOR FUTURE MANNED SPACE RESEARCH (√√)
CURRENT STATE AND YIELD PREDICTION	CROP INVENTORY AND LAND USE	1. LOCATION AND ACREAGE OF FOOD, FIBER, WOOD AND LIVESTOCK	H	E	H	E	H	NA	N	N	T	T	T	T	√	H	E	E	H	H	E	H	H	E	E	T	T	T	T	T	U	T	√	GEMINI, APOLLO 9, ERTS	NONE	√	√√
		2. LOCATION AND ACREAGE OF HARVESTED, FALLOW OR SOIL BANK LAND	H	E	H	E	H	NA	N	N	T	T	T	T	√	H	E	E	H	H	E	H	H	E	E	T	T	T	T	T	U	T	√	GEMINI, APOLLO 9, ERTS	NONE	√	√√
		3. LOCATION AND ACREAGE OF GRAZING, BROWSING, AND WILD LANDS	H	E	H	H	H	NA	N	N	T	T	T	T	√	N	H	H	H	H	H	H	H	E	E	T	T	T	T	T	U	T	√	GEMINI, APOLLO 9, ERTS	NONE	√	√√
		4. REPLICATION OF AIRCRAFT GROUND TRUTH EXPERIMENTS	E	N	E	E	E	NA	N	N	T	T	T	T	√	N	E	E	E	E	E	H	H	E	E	T	T	T	T	T	U	T	√	GEMINI, APOLLO 9, ERTS	NONE	√	√√
		5. SPECIES AND AMOUNT OF FOOD, FIBER, WOOD AND LIVESTOCK CROPS	E	E	E	E	E	NA	N	N	T	T	T	T	√	H	E	E	H	E	E	E	H	E	E	T	T	T	T	T	U	T	√	ERAP, USDA	NONE	√	√√
		6. SPECIES AND PALATABILITY OF FORAGE, WEEDS AND PHREATOPHYTES ON GRAZING AND BROWSING LANDS	E	E	E	H	E	NA	N	N	T	T	T	T	√	N	E	E	H	E	E	E	H	E	E	T	T	T	T	T	U	T	√	ERAP, USDA	NONE	√	√√
	YIELD FORECAST	7. BASIC SENSOR AND SIGNATURE RESEARCH THAT IS NEEDED	E	E	E	E	E	NA	U	U	U	U	U	U	√	H	E	E	E	E	E	E	E	E	E	T	T	T	T	T	U	T	√	ERAP, USDA	NONE	√	√√
		8. CHANGES IN ACREAGE OF CULTIVATED, FOREST AND WILD LANDS	H	E	H	E	H	NA	N	N	T	T	T	T	√	N	H	H	H	H	H	N	N	E	E	T	T	T	T	T	U	T	√		NONE	√	√√
		9. CHANGES IN NUMBERS AND DISTRIBUTION OF LIVESTOCK AND WILDLIFE	E	E	E	E	E	NA	N	N	T	T	T	T	√	N	E	E	E	E	E	E	H	E	E	T	T	T	T	T	U	T	√		NONE	√	√√
		10. AGE OF ORCHARDS, VINEYARDS AND FORESTS	E	E	E	H	E	NA	N	N	T	T	T	T	√	N	E	E	E	E	E	E	H	E	E	T	T	T	T	T	U	T	√		NONE	√	√√
	CROP AND RANGE VIGOR	11. SIGNATURES OF DISEASED OR INFESTED VEGETATION	E	H	E	E	E	NA	N	N	T	T	T	T	√	H	E	E	E	E	E	E	E	E	E	T	T	T	T	T	U	T	√	ERAP, USDA	NONE	√	√√
		12. LOCATION AND CAUSE OF MAJOR CROP FAILURES	E	H	E	H	E	NA	N	N	T	T	T	T	√	H	E	E	H	E	E	E	H	E	E	T	T	T	T	T	U	T	√	ERAP, USDA	NONE	√	√√
		13. LOCATION, TYPE AND EXTENT OF INSECT INFESTATION OF CROPS OR SOIL	E	E	E	E	E	NA	N	N	T	T	T	T	√	H	E	E	E	E	E	E	H	E	E	T	T	T	T	T	U	T	√	USDA	NONE	√	√√
		14. LOCATION, TYPE AND EXTENT OF DISEASE OF CROPS OR SOIL	E	E	E	E	E	NA	N	N	T	T	T	T	√	H	E	E	E	E	E	E	H	E	E	T	T	T	T	T	U	T	√	ERAP, USDA	NONE	√	√√
	ENVIRONMENTAL CONDITIONS	15. FERTILITY, SALINITY AND MOISTURE CONTENT OF SOIL	E	E	E	H	E	NA	N	N	T	T	T	T	√	N	E	E	E	E	E	E	H	E	E	T	T	T	T	T	U	T	√	USDA	NONE	√	√√
		16. INCLUSION OF BRACKISH WATER INTO SURFACE AND GROUND WATERS	H	H	E	H	E	NA	N	N	T	T	T	T	√	N	E	E	E	E	E	E	H	E	E	T	T	T	T	T	U	T	√	ERAP	NONE	√	√√
		17. SOURCES AND DISTRIBUTION MECHANISMS OF POLLUTION	E	E	H	E	E	NA	N	N	T	T	T	T	√	H	E	E	E	H	E	E	H	E	E	T	T	T	T	T	U	T	√	ERAP	NONE	√	√√
		18. LOCATION AND EXTENT OF EROSION, SILATION AND POLLUTION	H	E	H	H	H	NA	N	N	T	T	T	T	√	H	E	E	E	H	E	H	H	E	E	T	T	T	T	T	U	T	√	GEMINI, APOLLO 9, ERTS	NONE	√	√√
KNOWLEDGE REQUIREMENTS	IMPROVED PRODUCTION AND DISTRIBUTION	19. LOCATION AND ACREAGE OF POTENTIAL ARABLE, FOREST OR RANGE LANDS	H	E	H	H	H	NA	N	N	T	T	T	T	√	N	E	E	N	H	E	E	H	E	E	T	T	T	T	T	U	T	√	GEMINI, APOLLO 9, ERTS	NONE	√	√√
		20. NEED FOR IMPROVED LAND MANAGEMENT OR CONSERVATION	H	E	H	E	H	NA	N	N	T	T	T	T	√	N	E	E	H	E	E	E	H	E	E	T	T	T	T	T	U	T	√		NONE	√	√√
		21. NEED FOR BETTER TIMBER CUTTING AND LOGGING METHODS	E	E	E	E	E	NA	N	N	T	T	T	T	√	N	E	E	H	E	E	E	H	E	E	T	T	T	T	T	U	T	√		NONE	√	√√
		22. NEED FOR FOREST FIRE DETECTION AND FIGHTING METHODS	E	E	E	E	E	NA	N	N	T	T	T	T	√	E	E	E	H	H	E	E	N	E	E	T	T	T	T	T	U	T	√		NONE	√	√√
		23. NEED FOR PESTICIDES OR FERTILIZERS	H	E	H	E	H	NA	N	N	T	T	T	T	√	H	E	E	H	H	E	E	H	E	E	T	T	T	T	T	U	T	√	ERAP	NONE	√	√√
		24. LOCATION AND TYPE OF TRANSPORTATION ROUTES	H	E	H	N	H	NA	N	N	T	T	T	T	√	N	E	H	N	E	H	H	H	E	E	T	T	T	T	T	U	T	√		NONE	√	√√
		25. POTENTIAL ACCESS ROUTES TO RESOURCES THAT ARE DIFFICULT TO REACH	H	H	E	N	H	NA	N	N	T	T	T	T	√	N	E	H	N	E	H	H	H	E	E	T	T	T	T	T	U	T	√		NONE	√	√√
		26. WHERE AND BY WHOM ARE THE FOOD AND TIMBER RESOURCES CONSUMED	H	E	H	H	H	NA	N	N	T	T	T	T	√	N	E	E	N	H	E	E	H	E	E	T	T	T	T	T	U	T	√		NONE	√	√√
		27. WHAT IS THE WEATHER AND CLIMATE ALONG DISTRIBUTION ROUTES	N	H	N	E	N	NA	N	N	T	E	T	T	√	H	E	E	N	H	E	E	H	E	E	T	T	T	T	T	U	T	√	TIROS	NONE	√	√√
	DISASTER RELIEF MANAGEMENT	28. LOCATION, TYPE AND EXTENT OF STORM DAMAGE	E	E	E	H	E	NA	N	N	T	T	T	T	√	E	E	E	E	E	E	H	H	E	E	T	T	T	T	T	U	T	√	ERAP	NONE	√	√√
		29. LOCATION OF SALVAGEABLE TIMBER OR FOOD CROPS	E	E	E	H	E	NA	N	N	T	T	T	T	√	H	E	E	E	E	E	H	H	E	E	T	T	T	T	T	U	T	√		NONE	√	√√
		30. FLAMMABILITY INDEX OF FOREST AND RANGE	H	E	H	E	H	NA	N	N	T	T	T	T	√	H	E	E	H	H	E	H	H	E	E	T	T	T	T	T	U	T	√		NONE	√	√√
		31. LOCATION, DIRECTION RATE OF MOVEMENT OF FOREST FIRES	H	E	E	E	H	NA	N	N	T	T	T	T	√	E	E	E	H	E	E	H	H	E	E	T	T	T	T	T	U	T	√	ERAP	NONE	√	√√
		32. LOCATION OF MAJOR CROP FAILURES	H	E	H	H	H	NA	N	N	T	T	T	T	√	H	E	E	H	H	E	H	H	E	E	T	T	T	T	T	U	T	√		NONE	√	√√
	DATA COLLECTION AND ANALYSIS AND RESOURCE MODELING	33. NEW INSTRUMENTATION AND MEASUREMENT TECHNIQUES NEEDED	E	H	E	H	E	NA	U	U	U	U	U	U	√	E	E	E	E	E	E	E	E	E	E	T	T	T	T	T	U	T	√	ERAP, USDA	NONE	√	√√
		34. ABILITY OF ASTRONAUT/SCIENTIST TO RECOGNIZE AND TRACK A RESOURCE	E	E	E	E	E	NA	U	N	T	T	T	T	√	E	E	E	E	E	H	E	N	N	N	T	T	T	T	T	U	T	√		NONE	√	√√
		35. ASSEMBLY OF LARGE STRUCTURES, E.G., ANTENNAS IN SPACE	E	N	N	N	N	NA	E	E	U	U	U	U	√	N	N	N	N	N	N	N	H	E	H	T	T	T	T	T	U	T	√		NONE	√	√√
		36. MODIFICATION, CALIBRATION, REPAIRS, AND MAINTENANCE OF SENSORS IN SPACE	E	N	N	N	N	NA	E	E	U	U	U	U	√	N	N	N	N	N	E	E	E	E	E	T	T	T	T	T	U	T	√		NONE	√	√√
		37. MODELS NEEDED AND INPUT DATA REQUIRED	N	N	H	N	N	NA	N	N	N	N	H	N	√	N	E	E	E	N	N	N	N	N	N	T	T	T	T	T	U	T	√	USDA	NONE	√	√√
		38. MAN'S CAPABILITY FOR SELECTION, EVALUATION, ANALYSIS OF DATA IN SPACE	H	H	H	N	N	NA	U	U	U	U	U	U	√	H	E	E	E	H	N	N	N	N	N	T	T	T	T	T	U	T	√		NONE	√	√√
UTILIZATION OF KNOWLEDGE	NATIONAL AND INTERNATIONAL USE OF DATA	39. OWNERSHIP OF SPECIFIC FOREST RANGE AND WILD LANDS	H	E	E	H	H	NA	N	N	T	T	T	T	√	N	E	E	N	E	E	H	H	H	H	T	T	T	T	T	U	T	√		NONE	√	√√
		40. CONDITION AND ECONOMIC VALUE OF THE GRAIN OR WOOD IN A STAND	E	H	E	E	E	NA	N	N	T	T	T	T	√	N	E	E	N	E	E	H	H	H	H	T	T	T	T	T	U	T	√	USDA	NONE	√	√√
		41. ECOLOGICAL EFFECTS OF DAMS AND IRRIGATION PROJECTS	H	E	H	E	H	NA	N	N	T	T	T	T	√	N	E	E	H	H	H	H	H	H	H	T	T	T	T	T	U	T	√	USDA	NONE	√	√√
		42. OCCURRENCE OF SOIL EXHAUSTION OR OVERGRAZING	E	E	H	E	E	NA	N	N	T	T	T	T	√	N	E	E	H	H	H	H	H	H	H	T	T	T	T	T	U	T	√	USDA	NONE	√	√√
		43. RECREATION POTENTIALITIES OF FOREST, WATER AND WILD AREAS	H	E	H	H	H	NA	N	N	T	T	T	T	√	N	E	E	N	H	H	H	H	H	H	T	T	T	T	T	U	T	√	USDA	NONE	√	√√
		44. LOCATION OF FUTURE EXPANSION OF URBAN INTO RURAL AREAS	H	E	E	E	H	NA	N	N	T	T	T	T	√	N	E	E	N	E	H	H	H	H	H	T	T	T	T	T	U	T	√	USDA	NONE	√	√√
		45. WHERE SHOULD GREEN BELTS OR WILDERNESS AREAS BE ESTABLISHED	H	E	H	H	H	NA	N	N	T	T	T	T	√	N	E	E	N	H	H	H	H	H	H	T	T	T	T	T	U	T	√	USDA	NONE	√	√√
		46. POLLUTION OR OVERUSE ENDANGERING THE RECREATIONAL USE OF WATER OR FOREST AREAS	E	E	E	E	E	NA	N	N	T	T	T	T	√	N	E	E	H	E	H	H	H	H	H	T	T	T	T	T	U	T	√	USDA	NONE	√	√√
		47. WHAT INTERNATIONAL COOPERATION IN DATA ACQUISITION, AND APPLICATION IS NEEDED	H	E	H	N	H	NA	N	N	T	T	T	T	√	H	E	E	H	H	H	H	H	H	H	T	T	T	T	T	U	T	√	GEMINI, APOLLO 9, ERTS	NONE	√	√√

FOLDOUT FRAME

FOLDOUT FRAME 2

Target selection usually was deemed either essential or helpful. Although the coverage should be wide, once a resource area has been selected for observation, the future user of the data is probably interested only in specific areas, or even specific control points within the resource area. This is particularly true when working with ground truth sites. These sites are widely spread, but when an observer is operating over one of them he must be able to select his target so that he will have an accurate sensor check or calibration. Also, data are often collected for compilation as statistics, and the targets must be selected to be statistically representative so that it becomes valid to extrapolate the data to include the entire resource area, as is done now by the USDA (Reference 3.7-42).

Another important research objective is the replication of USDA experimental results from field mapping and aerial surveys. The in-orbit observer, then, must select the same sites for measurement as were used in the previous experiment. Much of the early work was with truth sites, and the same sites should be used again.

There are only three instances where target selection is not at least helpful. One of these is weather and climate along distribution routes, and the other two are concerned with onboard sensor calibration and maintenance. Weather and climate are such large-scale phenomena that precise target selection is not critical.

Repetitive coverage also is deemed helpful in the majority of cases. An entire crop can be planted, grown, and harvested in as little as three months, and it is impossible to monitor its size, vigor, and yield without at least weekly coverage. An exception is forest and range resources, which change much more slowly than field crops, so that yearly coverage would usually be satisfactory after the initial data have been established. Except for forest wildfire surveillance, complete coverage may be necessary only once every 5 to 10 years.

The low-orbit velocity-to-altitude (V/H) ratios are helpful, and even essential, for the precision sensing required for crop species and disease sensing. A current trend is to go to higher and higher aircraft flight altitudes to reduce V/H and increase total field of view. The orbital altitude of a space station is an extension of this trend. In many spectrometric experiments, the resource must be tracked long enough to make a spectrogram (e.g., 13 sec for an infrared interferometer), and a low V/H is essential. For most of the pre-screening groups of critical issues listed under Data Collection and Analysis, (Items 33 through 38, Table 3-43) V/H has no effect.

Since no other vehicles are involved in the measurements, relative velocity screening is not applicable.

The Space Environment Characteristics selection criteria (Table 3-39). do not impact significantly upon data taking in the Agriculture subdiscipline. The characteristics are deemed to be either of no effect, tolerable, or unknown. An example of a tolerable effect is fogging of film by space radiations. This can be avoided by properly designed film cassettes. An exception to this is in Data Collection, Items 33 to 38, Table 3-43, where the purpose of the research is to examine antenna erection and sensor calibration and maintenance in zero-gravity and vacuum environments. Here, gravitational effects and atmosphere are fundamental to the research. Atmospheric attenuation is bothersome, since it decreases signal amplitude and contrast, but it can be accounted for. Actually, for Pre-Screening Group No. 27, Table 3-43, related to weather along food distribution routes, attenuation is vital because attenuation by carbon dioxide in the atmosphere is the means of measuring the vertical temperature profile. In practice, however, the raw meteorological data will be acquired by the Meteorological subdiscipline, and the research objective here will involve developing specific information or climate along agriculture-related distribution routes.

All of the critical issues listed in Table 3-43 and pre-screening groups listed in Table 3-44 pass the space research applicability screening, as indicated in Table 3-44.

3.7.3.2 Screening for Manned Space Research Applicability

The agriculture subdiscipline is very much oriented to research and development and consequently depends strongly upon a scientist-observer, for data taking and quick-look evaluation. The presence of a scientist-observer, therefore, is deemed helpful to essential for almost all research objectives.

Realtime data analysis and evaluation are not crucial in this subdiscipline. Some of the exceptions are Pre-Screening Group No. 31 (Table 3-43) which concerns the location, direction, and rate of movement of forest and range wildfires, and Group No. 28, which concerns location, type, and extent of storm damage. Another is research in recognizing, acquiring, and tracking ground targets, Group No. 34, where the observer in space and the principal investigator at the truth site work in unison. The importance of the observer and principal investigator working as a research team is emphasized in the fourth column of the scientist-observer category (Table 3-44), where cooperation with the principal investigator on the ground is essential, or at least helpful, in most cases.

Crop inventory, land use, species identification, and disease monitoring all require data from several different sensors and from several spectral bands in any one sensor. Consequently, multiple sensor use and sensor mode selection are judged essential in most instances.

A development engineer onboard the spacecraft is deemed essential for objectives that require some research in signatures, signature recognition, and measurement technique development. Typical of these are Group No. 13, Table 3-43, (location and extent of insect infestation of crops or soil) and Group No. 15 (fertility, salinity, and moisture content of soil). The scientists and development engineers are not mere data takers; they are active members of a research team that also includes the principal investigators and the user on the ground.

Technicians are essential in all cases where the data are used directly. Most of the measurements must be precise, and the sensors must be kept tuned and calibrated. In the national and international uses of the data technicians are deemed only helpful because sensor data are only one of several kinds used in the research.

All factors that concern flight safety are designated as tolerable. None of the sensors, as far as is known, are safety hazards, and it may be confidently expected that any hazards that may develop can be reduced to tolerable levels by proper design. The same is true of mission performance degradation, except for effluent release. The observations should not be degraded by the effluents that may be released by the space station, but there is still sufficient doubt that effluent release is designated "effects unknown."

All pre-screening groups of critical issues in Table 3-44 also pass the manned space research applicability screening. For all objectives, man is rated helpful or essential in at least one area, and in no situation in his presence detrimental. None of the sensor support requirements or operational procedures pose a safety hazard to man.

3.7.3.3 Ongoing Programs

The relationship to other aircraft and spacecraft programs is very close, but none of the past or current programs completely satisfy any of the research objectives developed during the study. Related space programs are the Gemini earth photography, the Apollo 9 earth photography, and miscellaneous observations of earth taken on other space missions. A related ongoing space program is the Earth Resources Technology Satellite (ERTS). It is expected that the manned and the automated earth resources program will complement each other, since ERTS will have global coverage and uniform sun angle, and the space station will have lower altitude, higher ground resolution, and greater variety and flexibility of sensors.

The related aircraft program goes back to the 1930's, with the level of activity increasing during the past decade. Several of the recent activities, Table 3-45, were selected to illustrate the range of techniques, from the aerial photography of the Agricultural Stabilization Conservation Service through the research in species identification from radar imagery conducted at Kansas State University.

Table 3-45

REPRESENTATIVE CURRENT ACTIVITIES IN AGRICULTURAL REMOTE SENSING

Investigator	Technique	Results
1. Agricultural Stabilization Conservation Service, USDA	Aerial photography	Annually surveys about 200,000 acres; repeats every 5 to 10 years
2. Forest Service, USDA	Thermal IR imagery	Hot spots detected successfully; false alarm rate reduced
3. C. Wiegard, et al USDA, Weslaco, Texas	Spectrophotometric reflectance data	Discrimination of species very successful in 1,300- to 2,300-nanometer regions
4. V. Meyer USDA, Weslaco, Texas	Infrared spectrometry	Research promising and being expanded to include species identification
5. USGS/U.S. Army	Gemini photography	Demonstrates potential of agriculture surveys
6. P. Langley, et al USDA/NASA	Apollo 9 and synoptic aerial photography	Developed timber volume estimates of acceptable accuracy
7. C. Poulton Oregon State University	Aircraft and space photography	Developing notation and sampling techniques from photography
8. D. Belcher Cornell University	Aerial photography and data retrieval	Photographed 5,000 sq mi of New York and set up computerized data analysis and graphics
9. R. Colwell University of California (Berkeley)	Multispectral imagery	Able to identify species and differentiate healthy and diseased plants and livestock from low altitudes
10. R. Moore, D. Simonett Kansas State University	Radar imagery	Characteristic differences in reflectance observed; research continuing
11. D. Landgrebe, R. MacDonald Purdue University	Multispectral imagery	Computer program developed to identify crop species
12. W. Draeger University of California (Berkeley)	Infrared thermometry	Moisture determinable if soil type known; midafternoon best

Some of the critical issues in agriculture involve the replicating of the experimental results of the Department of Agriculture and NASA aircraft programs. The activities listed in Table 3-45 are typical of those whose results will be replicated. Remote sensing in the form of aerial photography is used extensively by agriculturists in the United States in the production of crop reports and of land use and land resource surveys. It is expected that the above agencies will incorporate space photography and data from non-photographic sensors in their regular agricultural surveys and publications.

Much research remains to be performed in remote detection and identification of disease, species identification, and soil moisture measurement. The research will seek unique signatures of diseases, species, soil moisture, etc., and study ways in which these signatures are affected by such factors of the environment as temperature, sun elevation, plant maturity, and season. Most of this will be done in laboratories and in controlled plantings, such as Weslaco, Texas, and the Laboratory for Agriculture Research at Purdue, Indiana, or at truth sites like the one at Buck's Lake, California. Once the techniques are developed for remote sensing at close range, they will be tested at orbital ranges.

Much progress has been made in computer modeling of agriculture and in automated crop species and crop vigor identification. Both the ground-based and space-based signature research will contribute raw data to the computer modeling program.

A major contribution of ERTS is the development of facilities and techniques to receive, process, and disseminate large quantities of data gathered from space. Both the multispectral television camera and the scanner will be aboard the space station, and the initial results from the ERTS program will guide the use of these sensors and the processing of their data in the space station program.

The critical issues related to crop inventory and land use (Pre-Screening Groups 1 through 6, Table 3-43), and to forest and range management, Groups 19 through 22, and 30 and 31, are covered by current programs of the USDA. Coverage is not complete, however, and current data gathering and interpretation are slower and more costly than desired. It is expected that the space program will gather more data with a higher information content at less cost than the field mapping currently employed. Cost saving will be realized particularly if the observations are extended to Central and South America.

According to a discussion with Dr. Robert Miller of the USDA in December 1969, the development of agriculture computer models is still under way. The issues concerning species and disease identification by computer modeling are not yet answered by current efforts, and space-gathered data will be available to help in completing the answer.

All of the critical issues and the pre-screening groups into which they were assembled are deemed to be candidates for future manned space research.

3.7.3.4 Grouping of Critical Issues into Research Clusters

Rationale for Grouping

The critical issues were grouped in two stages. They were first combined, on the basis of common data needs, into the 47 pre-screening groups listed in Table 3-43. The rationale for the initial grouping is discussed in Subsection 3.7.3. The second grouping gathered together the pre-screening groups that concerned common problems of agriculture, forestry, or range resources, resulting in the following five research clusters:

- 6-A/F-1 Crop Inventory and Land Use
- 6-A/F-2 Soil Type Mapping
- 6-A/F-3 Crop Identification
- 6-A/F-4 Crop Vigor and Yield Prediction
- 6-A/F-5 Wildfire Detection and Mapping

Remote sensing in the form of aerial photography is used extensively by agriculturists to classify, map, and measure vegetation, soils, or land use. The objective of research and development using manned space platforms is to gather data for the several Department of Agriculture programs that are of higher quality, contain more information, and are less expensive than the data now used. Some research areas are still in the research stage, even for ground-collected data. Examples are the detailed mapping of soils by type and fertility and the automatic identification of crop species from aerial strip photos taken in the visible and near-infrared regions. Here, the objective is to replicate the results of previous ground and aircraft research to determine which of the identification techniques are applicable to space data and to develop new techniques.

Crop Inventory and Land Use will determine the gross use of land under cultivation, such as agriculture, forest, range, and wild, and keep an up-to-date inventory of the use, as the USDA now does with aircraft and field mapping data. This area is very attractive for research at an early date because the spatial, spectral, and temporal resolution requirements are modest, sensors are available, and data interpretation techniques are well advanced. Forest and range condition is included in the Crop Inventory and Land Use cluster. The objective is to collect data on species, vigor, and yield for the managed and unmanaged forest, range, and wild lands. It is related to the cluster on crop vigor and involves similar research objectives but is often presented as a separate research area because the frequency of observation is far less and the management technology is different from that for cultivated crops.

Soil Type Mapping goes beyond land use to determine the suitability of soils for agricultural use. Climate, soil quality, and vegetation all are related, yet it is possible, with irrigation and fertilization, to sustain high production on naturally sterile soils. This cluster includes research in more detailed mapping of soils; monitoring for overgrazing, exhaustion, and pollution; and seeking out new soils that can be farmed.

The production-adjustment and land-use programs of the USDA require data on the crops actually being raised on agricultural lands throughout the country. The Crop Identification cluster will gather data for the remote identification of each crop species. The USDA also requires data on the expected yield of each species. Yield is determined by the number of acres planted in each species and by the vigor of the crop. Research will be performed on the remote sensing of crop vigor and interpretation of the data in terms of yield under the Crop Vigor and Yield Prediction cluster. These two clusters encompass the research objectives related to basic sensor and signature research, disease and insect infestation of crops and soils, air and water pollution, and the need for fertilizers, pesticides and irrigation.

Livestock and wildlife inventory is included in the Crop Identification research cluster. Identification will require considerable research before its feasibility is established. Particularly here, the research will be done over carefully instrumented truth sites by a closely coordinated team of scientists in space, in the field, and in the laboratory.

Remote identification is discussed in Paper No. 70-312 of Reference 3.7-19. The author states that ground truth is vital and that information is developed from several sources. The number of livestock is only part of the answer. Information is also needed on the acreage planted in white versus yellow corn, the acreage of grain harvested for feed, etc.

The way the pre-screening groups and the research clusters are related is illustrated in Table 3-46. Instances in which research clusters develop data that are useful to particular objectives are indicated by "X's". Each pre-screening group shown in Table 3-43 is covered by two or more research clusters. The only exception is Group No. 39, "Ownership of specific forest, range, and wild lands" (for tax-assessment purposes), which is covered only once, by 6-A/F-1, "Land use." On the other hand, several groups, such as No. 4 "Replication of past aircraft and ground experiments," and No. 33, "New instrumentation and measurement techniques needed," can utilize data from each of the five research clusters. The cluster that relates to the greatest number of objectives is 6-A/F-1, "Land use," because crop inventory and land use collect data on a wide variety of natural and man-made objects using several kinds of sensors.

TABLE 3-46 (page 1 of 5)

RELATIONSHIP OF PRE-SCREENING GROUPS OF CRITICAL ISSUES TO RESEARCH CLUSTERS -- AGRICULTURE AND FORESTRY

Research Area	Pre-Screening Critical Issue Group	Research Clusters: 6-A/F-1 Land Use	6-A/F-2 Soil Type	6-A/F-3 Crop Identification	6-A/F-4 Crop Vigor	6-A/F-5 Wildfire
Crop Inventory and Land Use	1. Location and Acreage of Food, Fiber, Wood, and Livestock	X				
	2. Location and Acreage of Harvested, Fallow, or Soil-Bank Lands	X	X			
	3. Location and Acreage of Grazing, Browsing, and Wild Lands					X
	4. Replication of Aircraft Ground-Truth Experiments	X	X	X	X	X
	5. Species and Amount of Food, Fiber, Wood, and Livestock Crops	X		X		
	6. Species and Palatability of Forage, Weeds, and Phreatophytes on Grazing and Browsing Lands	X		X		
Yield Forecast	7. Basic Sensor and Signature Research That is Needed	X	X	X	X	X
	8. Changes in Acreage of Cultivated, Forest, and Wild Lands	X		X		X
	9. Changes in Numbers and Distribution of Livestock and Wild Life	X				
	10. Age of Orchards, Vineyards, and Forests	X			X	

TABLE 3-46 (page 2 of 5)

Research Area	Pre-Screening Critical Issue Group	Research Clusters: 6-A/F-1 Land Use	6-A/F-2 Soil Type	6-A/F-3 Crop Identification	6-A/F-4 Crop Vigor	6-A/f-5 Vildfire
Crop and Range Vigor	11. Signatures of Diseased or Infested Vegetation	X		X		
	12. Location and Cause of Major Crop Failure	X		X	X	
	13. Location, Type, and Extent of Insect Infestation of Crops or Soil	X	X	X	X	
	14. Location, Type, and Extent of Disease of Crops or Soil	X	X	X	X	
Environmental Conditions	15. Fertility, Salinity, and Moisture Content of Soil		X		X	
	16. Incursion of Brackish Water Into Surface and Ground Waters		X		X	
	17. Sources and Distribution Mechanisms of Pollution	X			X	
	18. Location and Extent of Erosion, Siltation, and Pollution	X	X			

TABLE 3-46 (page 3 of 5)

Research Area	Pre-Screening Critical Issue Group	Research Clusters: 6-A/F-1 Land Use	6-A/F-2 Soil Type	6-A/F-3 Crop Identification	6-A/F-4 Crop Vigor	6-A/F-5 Wildfire
Improved Production and Distribution	19. Location and Acreage of Potential Arable Forest or Range Lands	X	X			
	20. Need for Improved Land Management or Conservation	X	X		X	
	21. Need for Better Timber-Cutting and Logging Methods	X				
	22. Need for Forest Fire Detection and Fighting Methods					X
	23. Need for Pesticides or Fertilizers	X		X	X	
	24. Location and Type of Transportation Routes	X				
	25. Potential Access Routes to Resources That are Difficult to Reach	X				
	26. Where and By Whom are the Food and Timber Resources Consumed?	X		X		
	27. What are the Weather and Climate Along Distribution Routes?	(6-M-6)				

TABLE 3-46 (page 4 of 5)

Research Area	Pre-Screening Critical Issue Group	Research Clusters: 6-A/F-1 Land Use	6-A/F-2 Soil Type	6-A/F-3 Crop Identification	6-A/F-4 Crop Vigor	6-A/F-5 Wildfire
Disaster Relief Management	28. Location, Type, and Extent of Storm Damage	X			X	
	29. Location of Salvageable Timber of or Food Crops	X			X	
	30. Flammability Index of Forest and Range					X
	31. Location and Direction Rate of Movement of Forest Fires					X
	32. Location of Major Crop Failures	X		X	X	
Data Collection and Analysis and Resource Modeling	33. New Instrumentation and Measurement Techniques Needed	X	X	X	X	X
	34. Ability of Astronaut or Scientist to Recognize and Track a Resource	X	X	X	X	
	35. Assembly of Large Structures (e.g. Antennas) in Space	X				X
	36. Modification, Calibration, Repairs, and Maintenance of Sensors in Space	X	X	X	X	X
	37. Models Needed and Input Data Required	X	X	X	X	
	38. Man's Capability for Selection, Evaluation, and Analysis of Data in Space	X	X	X		X

TABLE 3-46 (page 5 of 5)

Research Area	Pre-Screening Critical Issue Group	Research Clusters: 6-A/F-1 Land Use	6-A/F-2 Soil Type	6-A/F-3 Crop Identification	6-A/F-4 Crop Vigor	6-A/F-5 Wildfire
National and International Uses of Data	39. Ownership of Specific Forest, Range, and Wild Lands	X				
	40. Condition and Economic Value of the Grain or Wood in a Stand	X		X	X	X
	41. Ecological Effects of Dams and Irrigation Projects	X	X		X	
	42. Occurrence of Soil Exhaustion or Overgrazing	X	X		X	
	43. Recreation Potentialities of Forest, Water, and Wild Areas	X				X
	44. Location of Future Urban Expansion into Rural Areas	X	X			
	45. Where Should Green Belts or Wilderness Areas be Established?	X	X			X
	46. Pollution or Overuse end Angering the Recreational Use of Water or Forest Areas.	X	X		X	
	47. What International Cooperation in Data Acquisition is Needed?	X	X	X		

C-5

In some instances, a group benefits directly from one cluster and indirectly from others. An example is Group No. 14, "Location, type, and extent of disease of crops or soil." Research Cluster 6-A/F-4, "Crop Vigor," will contribute data directly, but 6-A/F-1, "Land Use," will contribute data indirectly, because when it distinguishes vegetation from barren ground, the stronger signal will come from the more vigorous vegetation. In 6-A/F-3 "Crop Identification" again, the data taken inherently will include observations of the relative vigor of the crop and will indirectly indicate the location, type, and extent of disease. Cluster 6-A/F-2, "Soil Type," will develop data on soil quality, and quality may be poor because of disease within the soil, not lack of fertility.

In some instances, direct measurement is only one of several inputs to the solution. This is true, for instance, in Group No. 20, "Need for improved land management or conservation," and Group No. 43, "Recreation potentialities of forest, water, and wild areas." The direct measurements will be used together with information on such influences as those of the general economic conditions, world markets, and population pressure to produce an answer. In the research area of Data Collection and Analysis and Resource Modeling (Groups 33 through 38), the intention is not to make measurements for direct use in agriculture, but rather to investigate the feasibility of doing precision measurements at all from a large, manned platform in earth orbit. The measurements themselves may never be used to produce agricultural information.

3.7.3.5 Brief Description of the Research Clusters

In summary, in the subdiscipline of Agriculture, Forest, and Range Resources, five research clusters were formed from the 115 critical issues judged to be suitable for a manned earth orbital research program. A brief description of these research clusters is presented at the end of Subsection 3.7. More detailed descriptions may be found in Appendix C.

3.7.4 Screening and Grouping of Critical Issues in Geography, Cartography, and Cultural Resources

For this study, it was decided that geography and cartography would be combined to constitute an integrated scientific and technical discipline* with separate but interdependent objectives. Geography is specifically concerned with the spatial relationships of human activity and natural processes. This includes the static and dynamic patterns of rural and urban settlement, land use, transportation networks, and other related data. Cartography, on the other hand, is the science of map making and map revision, and concerns itself with depiction of the physical surface of the earth on maps. As such, cartography's major contribution to progress lies in providing essential knowledge to a host of other scientific and engineering disciplines, including geography.

An overriding requirement of geography, as uncovered in the organized overview analysis, is to obtain additional up-to-date information on the many interactions between man and his environment. The need is for uniform data collected over short periods on a world-wide basis. Information presently available varies greatly (both in quality and quantity), is obsolete for many areas, and is completely lacking for other areas.

In the organized overview of geography and cartography, 159 critical issues (research objectives) were identified. As discussed previously in Subsection 3.7.1.1, these objectives were then examined to determine their candidacy for an earth-orbital experiment program. This screening process is summarized in Table 3-47.

The geographic and cartographic research objectives depend almost entirely on a capability for mapping and developing end-products derived in large measure from photography and other imagery. Such mapping studies include:

A. Thematic maps for:

1. Land-use planning.

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*In the Woods Hole Summer Study (1967-68) on the "Useful Applications of Earth-Oriented Satellites," for example, cartography and geodesy were considered together, and geography was allied with agriculture and forestry.

2. Population density and distribution assessment.

3. Transportation network density definition and location.

4. Urban and rural cultural, vegetational, and physiographic delineation and association.

5. Environmental calibration and change assessment with respect to interactions with man's activities.

B. Topographic maps on several scales.

C. Physical and cultural feature maps indicating the characteristics, distribution, and spatial relationships among land, water, and ice masses.

On the basis of common requirements for mapping, the 159 critical issues were grouped into three application areas, as follows:

A. The acquisition of data for mapping the earth's surface features and identifying changes resulting from man's cultural development.

B. The acquisition of data for the preparation of specifically designated small- to medium-scale geographic maps for multiple-user application.

C. The acquisition of data for the preparation of specifically designated large-scale geographic and cultural maps for multiple-user application.

3.7.4.1 Screening for Space-Research Applicability

The selections of critical issues in geography and cartography as candidates for space research was examined on the basis of the earth orbital and spacecraft environmental characteristics described in Subsection 3.7.1.2.

Analysis of the 159 critical issues (Table 3-47) indicates that the research objectives associated with 103 of them require that data be obtained by photography or photoimagery from orbit, in addition to or in conjunction with data obtained from other sources (such as ground sensors, other ground measurements, statistical information derived from census, and economic data) to form an articulated information system.

The primary criteria determining the applicability of space research to geography and cartography are (1) the wide-area geographic coverage possible; (2) the selection of targets, including those that were previously inaccessible; and (3) repetitive coverage to reveal trends in time-lapse phenomena, such as

FOLDOUT FRAME 1

Table 3-47

SCREENING OF CRITICAL ISSUES IN GEOGRAPHY AND CARTOGRAPHY

PROGRAM KEYS
A = ERTS A & B
B = NATIONAL OPERATIONAL METEOROLOGICAL SATELLITE SYSTEM (NOMSS)
C = NASA-MSC AIRCRAFT PROGRAM
D = MANNED MISSIONS (GEMINI, APOLLO, SKYLAB)

DEFINITION OF SYMBOLS
E = ESSENTIAL
H = HELPFUL
N = NO EFFECT
T = TOLERABLE
I = INTOLERABLE
U = EFFECTS UNKNOWN
NA = NOT APPLICABLE

			CRITICAL ISSUES	SPACE RESEARCH SELECTION CRITERIA: ORBITAL CHARACTERISTICS: ORBITAL ALTITUDES	WIDE AREAL (GEOGRAPHIC) COVERAGE	TARGET SELECTION	REPEATABLE GROUND TRACK	ORBITAL VELOCITY/ALTITUDE (V/H) RATIO	RELATIVE VELOCITY	SPACE ENVIRONMENT CHARACTERISTICS: GRAVITATIONAL EFFECTS	ATMOSPHERE (VACUUM)	METEOROIDS	ATMOSPHERIC ATTENUATION	COSMIC RADIATION	RADIATION BELTS	CRITICAL ISSUE IS SUITABLE FOR SPACE RESEARCH (√)	MANNED SPACE RESEARCH SELECTION CRITERIA: PARTICIPATION OF MAN: SCIENTIST/OBSERVER: REAL TIME DATA ANALYSIS AND EVALUATION	MULTIPLE SENSOR USE	SENSOR MODE AND PARAMETER SELECTION	COOPERATION WITH PRINCIPAL INVESTIGATOR ON THE GROUND	DEVELOPMENT ENGINEER: TARGET SELECTION	SENSOR OPERATION AND PARAMETER VARIATION	EVALUATION OF SENSOR DESIGN AND PERFORMANCE	COMPONENT QUALIFICATION TESTING	TECHNICIAN: EQUIPMENT SETUP, CHECKOUT, CALIBRATION	MAINTENANCE, REPAIR AND SERVICING OF SENSOR AND EQUIPMENT, CONSUMABLES	FLIGHT SAFETY: EXTERNAL ENVIRONMENTAL EXTREMES (RADIATION, TEMPERATURE, VACUUM, ETC.)	EXCEEDS PHYSIOLOGICAL LIMITS (WEIGHTLESSNESS, FATIGUE, DEHYDRATION, ETC.)	EXCESSIVE PSYCHOLOGICAL STRESS	AFFECTS CREW SAFETY (HIGH VOLTAGE, NOISE LEVEL, INFLAMMABLES, ETC.)	MISSION PERFORMANCE DEGRADATION: ACCELERATION DISTURBANCES (ATTITUDE CONTROL, CREW MOBILITY, ETC.)	EFFLUENT RELEASE (ENVIRONMENTAL CONTAMINATION)	REPETITIVE DUTY CYCLES (CONTINUOUS OR PRECISE OBSERVATIONS)	CRITICAL ISSUE IS SUITABLE FOR MANNED SPACE RESEARCH (√)	RELATIONSHIP TO OTHER PROGRAMS: PROGRAM ON WHICH PRELIMINARY INFORMATION HAS BEEN DEVELOPED	PROGRAM COMPLETELY SATISFYING EXPERIMENT REQUIREMENTS	RESEARCH REQUIREMENTS NOT SATISFIED BY OTHER PROGRAMS (√)	CRITICAL ISSUE IS CANDIDATE FOR FUTURE MANNED SPACE RESEARCH (√√)
ECONOMIC RESOURCES	WATER	6.3.1.1.1.1.1	How can the natural water supplies of wildlands, marshes, and other bird/animal sanctuaries be monitored?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.1.1.1.2	How can natural snow and watershed capacities be increased and the runoff controlled and monitored?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.1.1.1.3	How can topography be used more effectively for the generation of electrical power and control of silting of major dam and reservoir systems?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.1.1.1.4	How can potential irrigation water be located and possibly transferred to remote and reclaimed land areas?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.1.1.1.5	How can the distribution and rate of use of water supplies be monitored and presented in map form?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
	FOOD	6.3.1.1.1.2.1	What aspects of geography and cartography may be applied to the analyses of remote lands for food resources applications?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.1.1.2.2	How may remote lands be located, categorized, indexed, and displayed in map form?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.1.1.2.3	How can land in the higher latitudes be used more effectively for food reserves?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
	FOREST	6.3.1.1.1.3.1	How can geography be applied to the utilization of remote stands of timber?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.1.1.3.2	How can the location and configuration of remote timberlands be categorized, indexed and displayed in map form?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.1.1.3.3	How may geography and cartography be applied to more efficient monitoring and management of timberlands?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
TRANSPORTATION & COMMUNICATIONS	AIRCRAFT	6.3.1.1.2.1.1	How can urban land areas be more effectively used for airport and maintenance facilities?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.1.2.1.2	How can the hazards of air traffic be more effectively controlled in the urban areas?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																						
		6.3.1.1.2.1.3	How can the offensive noise problem be controlled during flight into and out of urban areas?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																						
		6.3.1.1.2.1.4	Can air terminals be more efficiently or remotely located and satisfy the demands of the business society?	H	H	E	H	H	T	N	N	N	T	N	N	√	N	E	H	H	E	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.1.2.1.5	How can access and egress be more effectively implemented in the design of internal urban terminals?	H	E	E	H	H	T	N	N	N	T	N	N	√	N	E	H	H	E	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
	RAILROADS	6.3.1.1.2.2.1	What aspects of geography/cartography can be applied to more efficient routing of existing and future railroads?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.1.2.2.2	What changes in the mode and techniques of rail travel could effectively enhance the efficiency?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	N/A																						
		6.3.1.1.2.2.3	How can monitoring of population movement and land use be used effectively for the location of railroad connections?	H	E	E	E	H	T	N	N	N	T	N	N	√	N	E	H	H	E	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.1.2.2.4	How may the development of railroad demands be monitored and portrayed?	H	H	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
	ROADS	6.3.1.1.2.3.1	What aspects of geography/cartography can be applied to more efficient routing of existing and future highways and internal urban accesses?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.1.2.3.2	How can geography be applied to the location of road materials and how may the sources be indexed and displayed?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.1.2.3.3	How can the most efficient types of roads be associated with geographic constraints and types of use?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																						
		6.3.1.1.2.3.4	How can the development of internal urban roads be efficiently monitored?	H	H	E	H	H	T	N	N	N	T	N	N	√	N	E	H	H	E	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
	WATER	6.3.1.1.2.4.1	What aspects of naval architecture can be directed toward the construction of subsurface highspeed cargo ships?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	N/A																						
		6.3.1.1.2.4.2	How might inland short water bodies be adapted to air terminals?	H	H	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.1.2.4.3	How can natural river systems be more expeditiously exploited as transport media, and how can these systems be effectively monitored, managed and controlled?	H	E	H	H	H	T	N	N	N	T	N	N	√	H	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
	TRANSMISSION LINES	6.3.1.1.2.5.1.1	How can pipelines be more efficiently routed and dependent upon local surface gradients?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																						
		6.3.1.1.2.5.2.2	How can pipelines be adapted to the high latitudes for the transport of liquids?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																						
		6.3.1.1.2.5.3.3	What aspects of pipeline transmission techniques could be applied to the transport of grains and/or other solids?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																						
		6.3.1.1.2.5.2.1	How can laser technology be applied to the transmission of power?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																						
		6.3.1.1.2.5.2.2	How can power be transmitted with greater efficiency?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.1.2.5.2.3	How can the capacity of the various carriers be significantly increased?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.1.2.5.2.4	How can power, phone, and other lines be eliminated from the urban environments?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
POPULATION	URBANIZATION	6.3.1.1.3.1.1	What significant impact does expanding urbanization have on the condemnation of usable agriculture and forest lands?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.1.3.1.2	How significant is the cement to land ratio of an expanding community on the erosion cycle and how might it be controlled?	H	H	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.1.3.1.3	How can the economics of urbanization be significantly increased?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.1.3.1.4	How may expanding communities be most advantageously monitored?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.1.3.1.5	How can optimum community configurations be predicted?	H	H	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
	MARKETING	6.3.1.1.3.2.1	What aspects of marketing are significantly affected by an expanding community and by settlement of new communities?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																						
		6.3.1.1.3.2.2	How can marketing techniques keep abreast of population migration?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																						
		6.3.1.1.3.2.3	How can mapping techniques be applied to the specific requirements of marketing?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
	LAND USE	6.3.1.1.3.3.1	What aspects of geography can be applied to the selection of potentially usable land areas?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.1.3.3.2	How can unused lands be located, categorized, and indexed for specific uses?	H	E	H	H	H	T	N	N	N	T	N	N	√	N		H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.1.3.3.3	How can cartographic techniques best be applied to all phases of land use from urban development to internationally controlled or monitored lands?	H	E	E	H	H	T	N	N	N	T	N	N	√	N	E	H	H	E	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
SOCIAL & CULTURAL	NATURAL DISASTER AVOIDANCE	6.3.1.2.1.1	How can the natural distribution of the Earth's surface features be related to the occurrence of natural destructive forces?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.2.1.2	What aspects of river dynamics can be explored to aid in the effective control of flood condition discharges?	H	E	H	E	H	T	N	N	N	T	N	N	√	H	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.2.1.3	How can abnormally high water conditions in the coastal environment be controlled for sustained periods?	H	H	E	H	H	T	N	N	N	T	N	N	√	N	E	H	H	E	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.2.1.4	How can disaster avoidance and management procedures be identified and initiated?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
	RECREATION	6.3.1.2.2.1	How can internal urban cultural and recreational facilities be created in rapidly expanding/deteriorating population centers?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T		A, C, D	NONE	√	√√
		6.3.1.2.2.2	How can the results of cultural achievement be more effectively applied to recreational facilities?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																						
		6.3.1.2.2.3	How can geographic relations be more effectively used for recreational pursuits?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
	MAN-LAND RELATIONSHIP	6.3.1.2.3.1	How can changing seasonal crop conditions be more efficiently dealt with by application of Geographic principles?	H	E	H	E	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.2.3.2	What and how are ecological trends being influenced by man's presence and cultural development?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.2.3.3	What is the rate of environmental change and how can this be measured meaningfully?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.2.3.4	How can population and traffic statistics be used for cultural studies?	H	H	H	E	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
	POPULATION PRESSURE	6.3.1.2.4.1	How can the problem of population density be controlled and/or modified in urban areas?	H	H	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.2.4.2	How can birth control education and program participation be effectively implemented in appropriate societies?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																						
		6.3.1.2.4.3	How can the world food supply be effectively distributed to areas of need and how can the distribution be more efficiently managed in heavily populated urban areas?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.2.4.4	How can the migration and distribution of urban population be monitored?	H	H	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
NATIONAL-INTERNATIONAL	LAND USE EVALUATION	6.3.1.3.1.1	How can the major geographic land areas of the world be identified, classified for use?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.3.1.2	How can the most appropriate use of specific land areas be determined?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.3.1.3	How should land areas be made more accessible to population centers?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																						
		6.3.1.3.1.4	How can land use on a world time and crop requirement be initiated for a world food exchange market?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																						
	DATA EXCHANGE	6.3.1.3.2.1	What data can be exchanged in support of international crop management for input to world food market?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																						
		6.3.1.3.2.2	What data can be exchanged for precisely determining available lands, transportation facilities, crop and forest inventories, population migrations, and population expansion?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																						
		6.3.1.3.2.3	What data can be exchanged in support of detailed and all inclusive surface mapping?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																						
	NATIONAL AND WORLD MAPPING	6.3.1.3.4.1	How can the mapping of dynamic features and processes be accomplished? What is the time frame?	H	E	H	E	H	T	N	N	N	T	N	N	√	H	H	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.3.4.2	What types of maps would be most useful to scientists and what scales, accuracies and time frames are required?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.1.3.4.3	How can maps displaying time variant entities be effectively produced and distributed for use?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
	GEOMORPHOLOGY	6.3.2.1.1.1	How was the Earth's surface topography developed?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.2.1.1.2	What Earth features prompted settlement of population groups?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.2.1.1.3	What effect did river systems have on the land and man's cultural development?	H	E	H	H	H	T	N	N	N	T	N	N	√	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	√	A, C, D	NONE	√	√√
		6.3.2.1.1.4	What restrictions or pressures did climate impose on societies and what were the reactions?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																						

FOLDOUT FRAME 2

FOLDOUT FRAME 1

Table 3-17 (Continued)

EVOLUTION	RESOURCES	6.3.2.1.2.1	What aspects of man's physical-chemical environment have necessitated or induced changes?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.2.1.2.2	What requirements/constraints has the animal kingdom imposed on the development of man and the environment?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.2.1.2.3	How did cultivation of crops affect the evolution and migrations of man and how has this progressed relative to population increase and land use?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.2.1.2.4	What effects did minerals have on the development of man's cultural and social societies?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
	POWER	6.3.2.1.3.1	What impact did controlled inanimate power have on the changes of man's culture and migration?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.2.1.3.2	How was the social structure advanced by power applied to resources and production?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.2.1.3.3	How did the development of power affect urban development?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.2.1.3.4	What effect is the expanding population and elevating culture having on power sources and their applications?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
STATE	BIOSPHERE	6.3.2.2.1.1	What is the ratio of unused to used land and the rate of change of this ratio?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.2.2.1.2	What percentage of unused lands is considered usable for cultivation?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.2.2.1.3	How has man changed the natural vegetation?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.2.2.1.4	What factors have dictated the major crops, the location and amounts of the crops?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.2.2.1.5	What is the present ratio of specific crops to world population and the rate of change of this ratio?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.2.2.1.6	What influence is exerted on the biosphere by the insect world?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.2.2.1.7	What is the present ratio of livestock to world population and the rate of change of this ratio?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
	PHYSICAL/CHEMICAL	6.3.2.2.2.1	What pollutants are evident in the atmosphere and in what percentage? What is their rate of change?	H	H	H	E	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.2.2.2.2	What general aspects of man's progress induce pollution and changes in topography and river systems?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T		A, C, D	NONE	✓	✓✓
		6.3.2.2.2.3	What is the relative importance of the coastline environment to man, river and mountain/plains environments?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.2.2.2.4	To what extent has man adjusted to latitude restrictions on the environment?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.2.2.2.5	What is the ratio of mineral availability to demand, oil, fresh water, etc.?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.2.2.2.6	To what extent and to what scales is the physical surface of man's environment depicted?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.2.2.2.7	How can the most important factors contributing to man's adaption to a changing environment be depicted in map form?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
	CULTURAL	6.3.2.2.3.1	What is the ratio of expansion of transportation facilities to the expanding population, (a) roads, (b) railroads, (c) waterways, (d) airlines/airports?	H	H	E	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	E	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.2.2.3.2	What influence of community development is imposed by each mode of transportation?	H	H	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.2.2.3.3	What relation exists between population movement and transportation facilities?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.2.2.3.4	What is the pattern of population migration and its rate of change?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.2.2.3.5	What is the rate of development in new communities?	H	H	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.2.2.3.6	What is the rate of expansion of existing populations, (a) countries, (b) states, (c) counties, (d) cities, (e) towns?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.2.2.3.7	How can man's cultural development be more adequately assessed and displayed?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.2.2.3.8	What factors of man's environment are the greatest deterrent to community expansion?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.2.2.3.9	What are the cement/soil/cultivation ratios of major urban developments?	H	H	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
	URBANIZATION	6.3.2.3.1.1	How do the various modes of transportation effect physical changes on the environment and population movement?	H	H	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, B, D	NONE	✓	✓✓
		6.3.2.3.1.2	What are the relative demands placed on the modes of transportation and how may effective control be enhanced?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.2.3.1.3	What aspects of transportation can be most efficiently modified and controlled, (a) type of power, (b) type of conveyor, (c) location of transportation, (d) frequency, etc.?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.2.3.1.4	How can industrial development in urban areas be related to the total community?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.2.3.1.5	How can pollution and waste from large population centers be effectively controlled?	NA	H	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.2.3.1.6	What aspects of urbanization impose the greatest restraints to orderly development?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
CHANGE	POWER	6.3.2.3.2.1	What innovations in the industrial power supply could significantly change the environment?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.2.3.2.2	How could microclimates be created and controlled by man?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, B, C	NONE	✓	✓✓
		6.3.2.3.2.3	How could solar radiation be effectively controlled for man's needs?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	F	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.2.3.2.4	What effect would be produced on the ecology of coastal areas supporting atomic power stations?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
	POLLUTION	6.3.2.3.3.1	How can pollution from industrial expansion be controlled, i.e., atmospheric/hydrologic?	H	H	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, B, C	NONE	✓	✓✓
		6.3.2.3.3.2	How is pollution related to the Earth's topography and climate?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, B, C	NONE	✓	✓✓
		6.3.2.3.3.3	How can waste disposal in large populated centers be significantly reduced or how can the rate of disposal be increased?	H	H	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.2.3.3.4	How is pollution affecting the coastal ecological environment?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
	LAND AND WATER USE	6.3.2.3.4.1	How can areas of drought and flood be more effectively controlled?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.2.3.4.2	How can vast forest regions be continuously monitored for fire and how can protection against fire be advanced and controlled?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.2.3.4.3	How can the hazards of pesticides and herbicides to the soil, rivers, and standing bodies of water be eliminated or controlled?	H	H	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.2.3.4.4	How can tillable lands be worked more efficiently and how can new marginal lands become domesticated?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.2.3.4.5	How can man best be educated to the problems of an ascending culture and the price for the industrial requirements to attain advanced cultural and social societies?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
CLIMATE	MACROCLIMATE	6.3.3.1.1.1	How does the global heat balance affect world climate?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, B	NONE	✓	✓✓
		6.3.3.1.1.2	How does the positioning of continents and oceans affect the major circulation?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.3.1.1.3	What aspects of man's ascending culture could affect world climate?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
	MESOCLIMATE	6.3.3.1.2.1	How does the regional heat balance affect regional climates?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, B	NONE	✓	✓✓
		6.3.3.1.2.2	How do mountain chains and plains provinces affect regional and local climates?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.3.1.2.3	At what rate is man adapting to latitude constraints on land use and settlement?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.3.1.2.4	How do man's activities affect the long term climate pattern?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, B	NONE	✓	✓✓
	MICROCLIMATE	6.3.3.1.3.1	How does the local heat balance affect local climates and can this be controlled?	H	H	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, B	NONE	✓	✓✓
		6.3.3.1.3.2	How does man's modification of the environment affect local climate?	H	H	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, B	NONE	✓	✓✓
		6.3.3.1.3.3	How do great population centers affect local climates?	H	H	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, B	NONE	✓	✓✓
RESOURCES	MINERALS AND MANAGEMENT	6.3.3.2.1.1	How are the world mineral and petroleum inventories affected by the increasing and shifting population?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.3.2.1.2	What effects do the Earth's mineral resources have on man's control of the environment and social structure?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.3.2.1.3	What constraints are imposed upon cultural advancement, population increase, and migration by available minerals and oil?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.3.2.1.4	How do man's migration and settlement patterns exert an influence on mineral resources?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.3.2.1.5	How can the supply of strategic and necessary minerals be effectively managed for man's increasing needs?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
	WATER	6.3.3.2.2.1	How do man's migration and settlement exert an influence on water resources?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.3.2.2.2	Do water resources influence man's present cultural development?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.3.2.2.3	What is the rate of depletion of natural water supplies in areas of population pressure?	H	E	H	E	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.3.2.2.4	What is the effect of man's cultural development on surface water bodies?	H	H	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.3.2.2.5	How can urban development be related to available water supplies?	H	H	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.3.2.2.6	How can urban water supplies be increased or effectively controlled?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
	LAND AND MANAGEMENT	6.3.3.2.3.1	How will the expanding population affect the decisions on tillable versus urban development land?	H	H	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.3.2.3.2	How can land in the higher latitudes be used effectively?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.3.3.2.3.3	What effect is exerted by man and his environment on land usage?	H	H	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.3.2.3.4	How do settlement patterns relate to land use?	H	H	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.3.2.3.5	What are the effects of urban development on erosion of the land?	H	H	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
ECOLOGY	WATER	6.3.3.3.1.1	What effect is exerted on the coastal and inland water body ecologic environments by industrial warm water waste?	H	H	E	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	E	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.3.3.1.2	What effect do river/dam systems have on the biosphere?	H	H	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.3.3.1.3	How are pollutants derived from population increase and the cultural and social advancement of man affecting the water ecologic system?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
	LAND	6.3.3.3.2.1	What effect is exerted on micro-macro organisms by expanded land use and pollution by man?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.3.3.2.2	What effects do herbicides/insecticides have on natural vegetation and soils?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.3.3.2.3	To what extent do man's modifications of the environment for expansion affect the land and ecologic system?	H	H	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
	AIR	6.3.3.3.3.1	How are all ecologic systems affected by atmospheric pollution?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.3.3.3.2	What aspects of population increase and migration most affect the airborne ecology?	H	E	H	H	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓
		6.3.3.3.3.3	What effect is exerted on the air ecologic system by the pollution of water and soil?	H	E	H	E	H	T	N	N	N	T	N	N	✓	N	E	H	H	H	H	H	H	H	H	N	N	N	N	N	T	T	✓	A, C, D	NONE	✓	✓✓

FOLDOUT FRAME 2

urban sprawl, transportation linkage, traffic flows, population migration, and the results of catastrophes (floods, earthquakes, fires, etc.). The balance of the orbital criteria are not significant, nor are the criteria relating to the space environment.

In summary, 103 critical issues were retained as suitable for space research in either manned or unmanned space flight.

3.7.4.2 Screening of Critical Issues for Applicability to Manned Space Research

The selection of critical issues in geography and cartography as candidates for manned space research (Table 3-47) was analyzed on the basis of criteria set forth in Subsection 3.7.1.3. The grouping of criteria focuses on human participation, flight safety, and mission performance degradation.

Starting with the assumption that a manned space station exists and that it is research-mission-oriented and carries special equipment to measure and observe characteristics of the earth's surface, the role and participation of man is then examined on the basis of three fundamental types of interactions that he would have with the application areas in geography and cartography. His functions will be that of a scientist-observer, development engineer-operator, and technician-serviceman.

The scientist-observer role is phenomenon-oriented and includes the selection, observation, and description of natural (programmed or unexpected) and man-made phenomena, and two-way communication with the ground.

Both by visual observation and by the analysis and interpretation of pictorial and other data acquired by the various sensor systems under his control, the scientist-observer can detect, recognize, select, discriminate, analyze, interpret, and correlate various phenomena in a manner for which he is uniquely suited by nature and by training. His ability to respond to transitory, nascent, or newly discovered targets of opportunity, such as floods, fires, and earthquakes, will be enhanced if he can have personal contact with the realtime data flow. The assumption is that proper onboard data displays will be available.

The role of the development engineer-operator is both phenomenon- and equipment-oriented. For certain targets of opportunity, such as a newly discovered fire, a developing flood-situation,*or an earthquake, high-resolution measurements will be needed and will require an array of instruments that would not be deemed necessary under normal circumstances. Given a moderately inclined low-altitude orbit, there will be little chance for second looks during subsequent orbits. Consequently, the proper pointing of sensors and simultaneous measurements will be required for a short period of time. The operator role would also require that before-and-after measurement calibrations be made.

Thorough testing of instrumentation in actual, rather than ground-based simulated, conditions for research and development purposes as well as for later use in unmanned satellites is a natural role for the development engineer-operator. In view of the size and available power of a manned space station, the assumption is that prototype equipment would not require miniaturization.

For example, when several design choices are available, as they usually are in the early stages of development of new or improved instrumentation, a working breadboard could be installed on the station. The manned function would involve performing manual functions, analyzing and discussing the data in two-way communication with ground personnel, and making <u>in situ</u> modifications. Later, engineering shakedown and qualification testing would involve operation of the final device.

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*The application of space photography to natural disasters was substantiated in the case of the Ouachita River Flood in Arkansas and Louisiana in March 1969, which was photographed by Apollo 9. For the first time, space photography showed an entire flood. The photo is presented being analyzed for its usefulness in flood studies.

For geography and cartography, the role of man as a technician-serviceman is equipment-oriented and is viewed from the standpoint of man's ability to assemble, position, calibrate, and align equipment initially following launch and as required thereafter. The role is also viewed on the basis of man's ability to maintain and repair equipment, as well as to retrieve and replace equipment in a EVA mode from manned as well as from unmanned spacecraft. While this role requires little research orientation, it does permit man to perform his research function in space.

For geography and cartography, much of the analysis of the criteria relating to man's participation results in subjective judgements regarding the degree of technical sophistication that may be required or justified to replace him by unmanned automatic or ground-controlled systems. Simple tasks requiring, for example, the turning on and turning off of a camera or other sensory device at predetermined times, have for some time been commonplace for unmanned satellites On the other hand, the detection, recognition, and monitoring of targets of opportunity may be too difficult for an unmanned system, and the replacement and repair of instrumental components would appear to be prohibitive.

In analyzing the specific criteria relating to man's participation in space research on the basis of the application areas for geography and cartography, therefore, little reason can be found for man not to be there. Neither does the need for man appear to be absolute; rather, it seems that man's participatory role in space will help satisfy the long-range scientific and technological goals for geography and cartography and the critical issues that derive from them.

With respect to the criteria relating to flight safety and mission performance, as discussed in Subsection 3.7.1.3, previous experience in manned earth-orbital missions seems to indicate that the environmental extremes of space can be considered tolerable. No measurements are contemplated that would exceed physiological limits, cause excessive physiological stress, or affect crew safety.

Acceleration disturbances brought about by crew mobility are deemed tolerable, as are the effect of the release of effluents. In the latter case, however, optical frontal elements must be protected during nonmeasurement or non-observation periods. At the present time, there appears to be no requirement for any grouping of critical issues for repetitive duty cycles that would require continuous, high-precision observations with man constantly in the loop.

Summarizing the foregoing discussion, man emerges as being potentially useful but not necessarily essential. There are no application areas where man's presence is intolerable. Neither do there appear to be any flight safety or mission performance degradation criteria that appear to be intolerable. As a result, the 103 critical issues that were deemed suitable for space research in Subsection 3.7.4.1 were retained.

3.7.4.3 Contributions of Ongoing Programs

The NASA Earth Resources Survey Program is presently progressing toward the launch of the first Earth Resources Technology Satellite (ERTS-A) in 1972. Some prototype experiments have been conducted through the aircraft program, and some earth-oriented space photographs have been obtained from the manned spaceflight programs. All of these data sources and experimental programs have been developed by NASA in close cooperation with other governmental departments, such as Agriculture, Interior, Commerce, and Navy.

The Department of Interior's EROS program is most closely allied with the critical issues for geography and cartography. This program aims at improving the use of aeronautical and space vehicles for advancing capabilities in these and other disciplines.

All of the manned space programs have had experiments relevant to geography and cartography. Synoptic black-and-white and color photographs of terrain were obtained on most of the Gemini missions.

Of more significance to geography and cartography, however, was Apollo 9 Scientific Experiment No. S-065, which was flown in March 1969. This investigative effort was concerned with the feasibility and rationale of using simultaneous multiband photography for making earth resources surveys from space. The results of this photography, in addition to high-altitude-aircraft color infrared photography, have been aimed at defining surface parameters that could be observed at various ground resolutions (e.g., 100 to 200 ft and 300 ft). Using Apollo 9 photographs, tests have shown that vertical space photographs can be readily adapted as photographic bases to standard 1:250,000 topographic maps. The photomaps, containing more information on land use for the map user, also update and increase the accuracy of the map.

Contributions of the foregoing programs have been extremely valuable in meeting the information requirements of the critical issues. Despite this, however, much basic understanding of the content of remote sensor-derived data remains to be developed. Some of this relates to the detection, identification, recognition, and interpretation of phenomena for which sufficient ground-truth information exists. The extension of this understanding and its application to phenomena in geographic regions where little or no ground-truth information is available will require much additional research.

In summary, while the relationship of laboratory, field, aircraft, and spacecraft programs to the critical issues in geography and cartography is generally close, neither past nor current programs significantly satisfy the critical issues developed during the present study. Therefore all of the 103 issues deemed suitable for manned space research were retained.

3.7.4.4 Grouping of Critical Issues into Research Clusters

In the organized overview analysis, correlation of NASA goals and objectives and correlation of scientific and technological goals for geography and cartography resulted in identifying major subobjectives and specific application areas related to each subobjective. Within each application area, specific critical issues (research objectives) have been defined.

As discussed in Subsection 3.7.4, all of the critical issues deemed suitable for space share a common requirement for mapping to develop information required. These data requirements are also related from the standpoint of observables and commonality in instrumentation. Typical of this commonality are urban transportation networks and urban-area land use. Clearly they are part of the same scene and require the same basic photography and other imagery. With respect to instrumentation required to gather information on the observables, essentially the same instrument grouping applies to all application areas (metric panoramic, and multiband cameras, a multispectral infrared line scanner, a radar imager, and a laser altimeter). Differences among imaging systems relate primarily to such system parameters as focal length, image size, image scale, obtainable ground resolution, image resolution, field of view, ground coverage, and spectral band.

Through commonality, therefore, it is possible to combine the requirements of 61 of the 103 candidate critical issues into a single research cluster that serves as a basis for experimental research in geography and cartography in space. The other 42 critical issues were judged to be more appropriate to other research clusters derived in other subdisciplines of Earth Observations, as shown in Table 6, Appendix B.

3.7.4.5 Brief Description of Research Cluster

In summary, in the subdiscipline of Geography, Cartography, and Cultural Resources, one research cluster was formed from the 103 critical issues judged to be suitable for a manned earth-orbital research program. A brief description of this research cluster is presented at the end of Subsection 3.7. A more detailed description may be found in Appendix C.

3.7.5 <u>Screening and Grouping of Critical Issues in Geology</u>

The purpose of the overview analysis (Appendix A) is to:

A. Relate geologic factors to the needs of man.
B. Provide information on the related-factor knowledge level, or the practicality of developing the several geologic issues via remote sensing.

C. Relate the more esoteric problems of geology to the broader categories of knowledge.

D. Provide an organizational base from which geologic research areas can be derived.

Five major research areas in geology were derived from overview analysis. In their tentative priority of order, these are:*

6.4.1.1.1*	Rock and Soil Type Identification
6.4.1.1.5	Mineral and Oil Deposit Discovery
6.4.1.1.2	Use of Earth's Crust to Store and Condition Commodities and Waste
6.4.1.1.3	Geologic Disaster Avoidance
6.4.1.1.4	Utilization of Geothermal Energy Sources

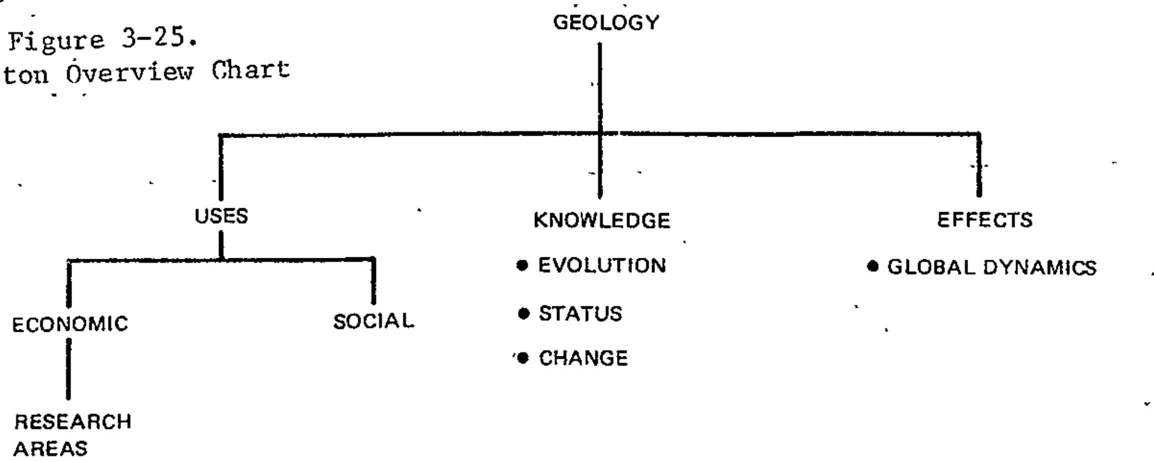
As of this date, these areas merit attention as comprising the most intimate interface between society and geology. These areas also appear to embody the substance of geology's immediate potential contribution to society. In addition, there seems to be a current concensus as to their value (at least for those of higher priority). Additional research areas may be selected from the organized overview chart as the work continues, but it is expected that they will be subsidiary, marginal, or technically more remote.

It will be noted that the research areas are all derived from the economic area of the chart, as indicated in Figure 3-25, which is a skeletal version of the overview chart. There are many advanced critical issues in the areas of evolution, status, change, and global dynamics. These are the great unresolved technical issues of geology today. Many of these relate to crustal stability on a massive scale. The geologic profession is extremely interested in defining experiments that would have a likelihood of resolving these issues. The research areas selected (such as geologic disaster avoidance) will depend on advances in geologic theory. All of the more theoretical questions are thus considered as being intrinsic to the solution of the selected research areas.

*Numbers correspond to those in Table 6 of Appendix B.

The great research issues have not been ignored.

Figure 3-25.
Skelton Overview Chart



The overview analysis calls for the research areas to be broken down to the experiment level. It also calls for the specification of such considerations as remotely observable phenomena, wavelengths to be used, and appropriate equipments. In geology, these specifications must be provided with certain reservations related to the general level of geologic and remote-sensing knowledge and to the relationship between them. The problems are formidable and must be considered at this point.

One of the most serious obstacles to the automatic recognition of geologic phenomena from their spectral signature can be termed the number-of-variables problem. Although this problem is mundane, it is very troublesome. Any pure sample of a given type of rock, with given physical characteristics and under given conditions, will have a unique spectral signature. By examining the signatures of pure samples, it is possible to distinguish each rock sample. The problem is that the instantaneous field of view of the sensor does not see a pure sample. Figure 3-26, taken from reference 3.7-29, shows the spectral signature of a wet cobblestone road. Figure 3-27, from the same source, is the spectral signature of a cargo truck. If the same truck were sitting on the same road and if the field of view contained equal parts of each, the signature should look about as shown in Figure 3-28, which was generated synthetically. To recognize a truck, the spectral return would have to be able to correlate with a distribution, such as the one given in Figure 3-27, Figure 3-28, or any number of other distributions, depending on whether the

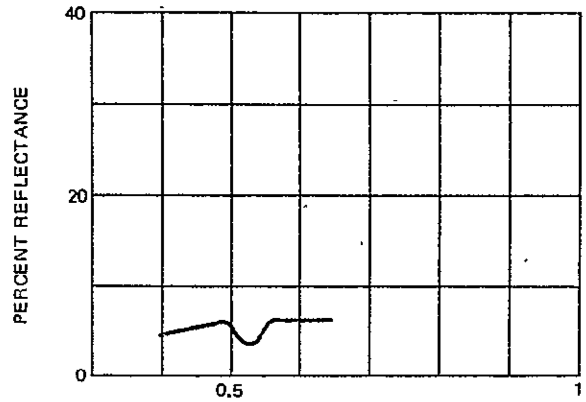


Figure 3-26. Wet Cobblestone Road*

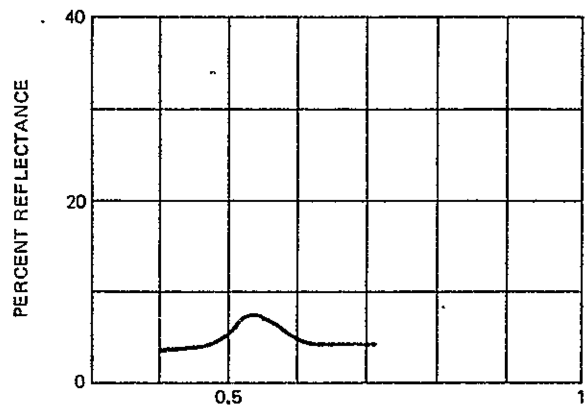


Figure 3-27. East German Cargo Truck*

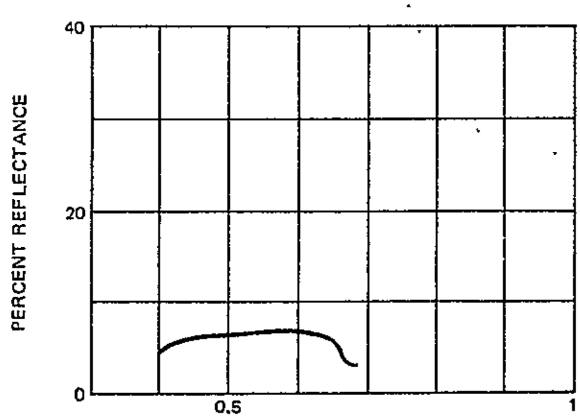


Figure 3-28.
East German Cargo Truck Parked on a Wet Cobblestone Road

*TAKEN FROM "TARGET SIGNATURE ANALYSIS CENTER DATA COMPILATION," DOCUMENT AD 489-968, UNIVERSITY OF MICHIGAN, WILLOW RUN LABORATORIES, 1968.

truck was on a wood plank road, an asphalt road, a concrete road, a dirt road, etc. Each road would have variables, depending on such considerations as temperature and wetness. In short, the number of parameters in the large instantaneous field of view (or related to one terrain element) is very large. Table 3-48 lists some of the elements that can reasonably be expected to influence the spectral distribution of the return. When all of these different factors are considered, the signature recognition problem as an isolated entity is very difficult (and perhaps impossible) to solve. Taking only soil-rock factors, vegetation, and water factors of the surface, the problem may already be too complex. Other problems, however, must also be considered.

In Reference 3.7-4, page 10 (geology), the basic multisensing problem is summed up (as of 1969) as follows: "The basic problem in applying remote-sensing data lies in relating the electromagnetic and force-field data to rocks and soils, and in turn, to the analytical process, as used by exploration geologists. How can these data assist the field geologist in his search for new mineral wealth?" Thus, it is seen that there is a definite lack of knowledge in the use of multispectral sensing in relation to geology.

There is also the problem of the general level of geologic knowledge: the cause of volcanos is not known; the reasons for tectonic activity are not understood; and the composition, density distribution, and state and temperature of the earth's mantle and core can only be theorized. Thus, a gain in basic geologic knowledge is required for some research areas.

Another problem that is more severe to geological investigation than to the other earth survey disciplines is that some of the materials sought are buried deep in the ground where no sensor can penetrate and receive intelligible data.

Classifying rocks and soil is also a problem. Rocks are not easily classified into a few simple types. Rocks vary continuously through various parameters and gradually turn from one type to another. It may be necessary to be able to determine the chemical-mineral content of the material along with other descriptors. A lesser problem is that of spatially organizing the results (usually into the form of a geologic map).

Table 3-48

FACTORS INFLUENCING SPECTRAL SIGNATURES

Chemical composition of rock and soil	Multiple types in field of view
Mineral composition of rock and soil	Type of vegetation present
Internal microstructure	Extent and distribution of vegetation
Jointing	Health of vegetation
Grain size	Maturity of vegetation
Crystal size	Amount of water present
Degree of consolidation	Impurities in water
Terrain shape	Presence of animals
Age of materials	Presence of man-made objectives (complex in the extreme)
Terrain texture	Atmospheric disturbances
Presence of additives, such as fertilizer	"Crossover" and temperature factors
Surface factors (such as hard-packed and newly plowed)	Solar illumination angle
	Aspect angle

Another problem which many geologists consider very severe is the limited spatial resolution attainable from space. One-hundred-foot resolution is attainable in the visible region, with somewhat smaller resolution achievable at the longer wavelengths. In terms of required resolution, however, a 2-ft capability is needed to resolve dikes and other small geologic features. These problems are severe. It seems clear that, in aggregate, they force the developments into a certain pattern for solution. Since no quick and easy key can be used today to solve geologic problems, the solution lies in a comprehensive understanding of the geology discipline. To illustrate, consider the first three research areas listed, in which lack of general geologic knowledge is not a factor. None of the above problems prevent the field geologist from solving geologic problems and preparing geologic maps or answers for these areas.

Nor do these problems prevent the photointerpreter from solving the same geologic problems with very little field sampling. Certain characteristics of these successful methods should be considered in relation to the multispectral analysis developments.

The photointerpreter uses the convergence-of-evidence approach to that useful art that is also comprehensive. Photographic interpretation is the function of examining photographic life images, identifying objects or conditions, and evaluating the significance. The photointerpreter has an immensely broad background that includes geology, geomorphology, timber and vegetation sciences, hydrology, soil sciences, crop identification, agricultural practices, range management, geography, demography, oceanography, meteorology, transportation and communication factors, and herds and wildlife. This kind of background is necessary because of the correlation between various factors from diverse disciplines. The photointerpreter uses his knowledge to generate a structure of deductions that leads to conclusions, certain vegetation grows only in certain soils, at certain altitudes, and under certain ground water and climatic conditions. The photointerpreter may then take into account the present techniques of sensitive deep-seated minerals: (1) to observe what can be fairly easily observed, (2) to synthesize a theory or model of what geological processes are responsible for the observed phenomena, and (3) to deduce the presence of the deep-seated minerals at an inferred location. Understanding these many related factors allows the photointerpreter to deduce what cannot be seen from what can. As the general understanding of the geographical area increases, many more visible features take on significance, and an iterative learning operation results. Finally the interpreter is able to generate the desired answer.

All of the data are used. Thus it is seen that for this kind of approach, multiple parameters work in favor of the enterprise, not against it. Inability to sense deep-seated minerals or oil directly does not prevent their discovery.

The resolution problem in photointerpretive work is much like the one in multispectral analysis. The photointerpreter must often classify solid by grain size, to determine whether a deposit contains gravel, sand, silt or clay. The grain size of clay ranges from less than 0.0002 to about 0.005 mm, silt from about 0.005 to 0.05 mm, sand from 0.5 mm to about 1 mm, and fine gravel from 1 mm to 2 mm. Imagery taken from 10,000 ft cannot resolve any of these grain sizes, but the photointerpreter can nevertheless often distinguish among the soils. Many formations that are identifiable by stereoscopic examination of photographs are known to have materials of a given grain size. A wind-blown loss can be so recognized; it is a silt. A true landslide indicates a preponderance of clay in the soil. The cross-sectional configuration of a stream bed can be used to identify clay versus more permeable materials. If a muck pocket is identified, the surrounding material is permeable because muck does not form in clay.

Inferring the presence of sand by recognizing a sand dune is typical of photointerpretation. The presence of sand is perhaps the answer to the problem. The alternative identified has been termed by several authors as the "surrogate." In this case, then, the sand dune is the surrogate.

It seems that the use of surrogates is indispensable to the process of photointerpretation. What alternative can be mentioned with respect to the spatial resolution problem of grain sizes discussed above? What alternative can be suggested for the solution of the spatial resolution problem in the spectral domain? The development of spectral-domain surrogates is difficult because this domain is less intelligible to the photointerpreter than the usual, visible-range, spatial domain. It would seem that such surrogates could be developed using photointerpretation as a control. To put the data in optimum form for such an operation, the nonvisible-range data and derivations therefrom should be put in the same spatial configuration as the imagery used by the photointerpreter. The surrogate approach may also aid in coping with the multitude-of-parameters problem. If a certain large-scale phenomenon can be recognized, the effect of such a phenomenon on the spectral signature can perhaps be eliminated. Also, if certain other phenomena are known to generally associate with the large-scale phenomenon, their effects can deducted on a trial-and-error basis. The remaining signal is the one that is tested against the signature library. As individual factors are definitely identified, the signal is modified, leaving only what is still unknown, always using known relationships to guide the logic. The optimum system might utilize logic from both multispectral analysis and photointerpretation.

The need for developmental work in the areas of basic geology, photointerpretation, and multispectral analysis makes it difficult to be specific in answering many of the relevant questions. Figure 3-29 suggests an interrelated development cycle for this research area.

In summary, the problems related to the advancement of geologic knowledge by means of manned space operations are formidable. Conversely, the geologic state-of-the-art could benefit greatly from data realized from a new perspective, at a different scale, and from a new domain (the spectral). There are parallel examples in the area of photointerpretation that give reason to expect that the problems of geologic exploration and mapping from space can be solved to mankind's advantage.

3.7.5.1 Screening for Space Research Applicability

The five major research areas listed in Subsection 3.7.5, as well as the four listed below, were screened for space-research applicability.

6.4.2.2.1	A supporting research area. Identification of land forms associated with dynamic processes and identification of structural forms by analyzing associated vegetation.
6.4.2.3.2	A marginal research area. Monitoring the relative movements of major fault systems.
6.4.3.2.2	A research area covering effects of continental size and a variety of smaller features on the earth's gravity field.
6.4.3.2.3	A research area covering effects of continent size and a variety of smaller features on the earth's magnetic field.

The effects of the following factors were considered in assessing the individual research areas for space research: orbital altitudes, wide areal coverage, target selection, repetitive coverage, orbital velocity/altitude (V/H) ratio,

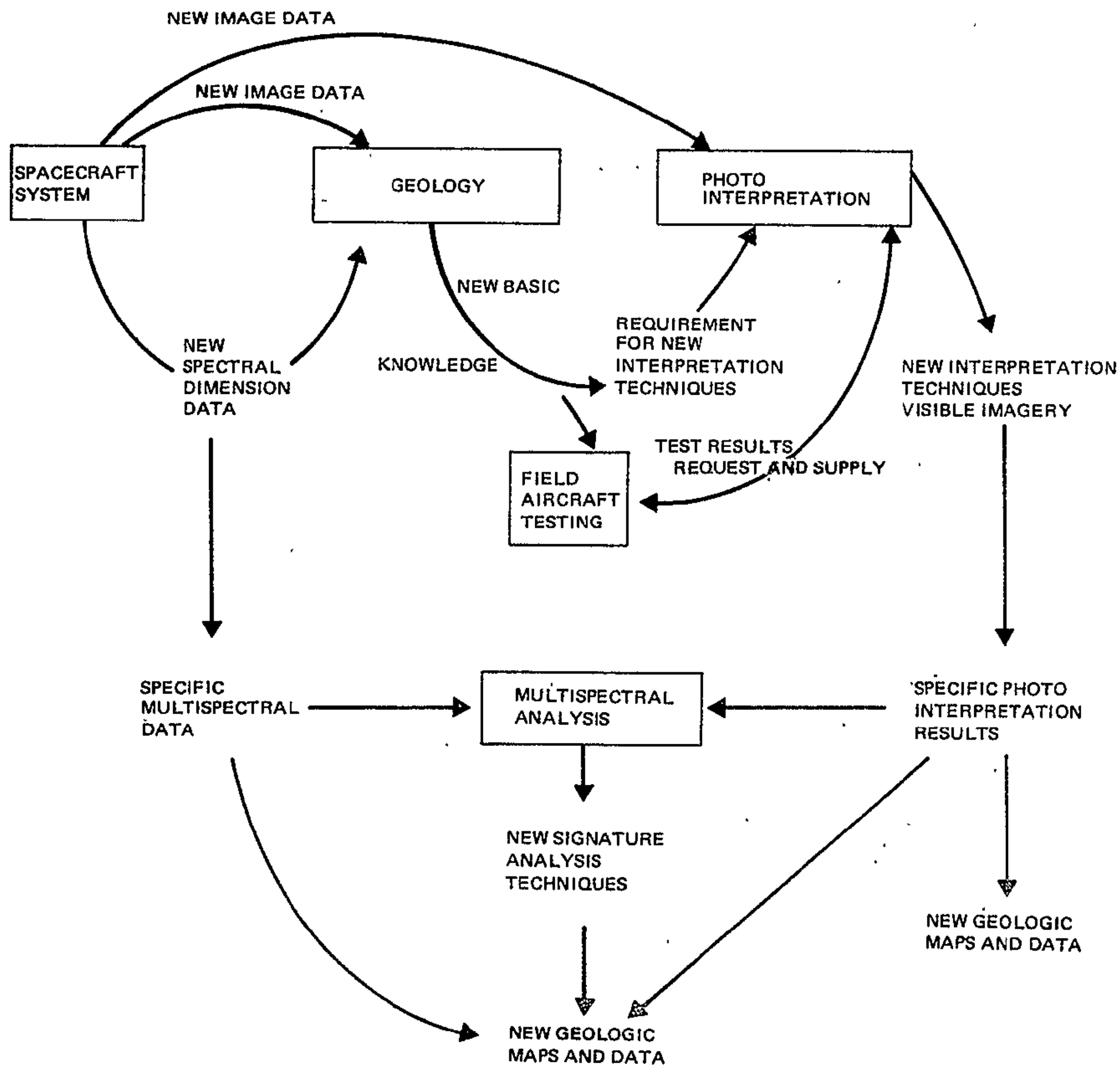


Figure 3-29.

Suggested Development Cycle for Research in Geology gravitational effects, atmospheric conditions at the space research facility, meteoroids, atmospheric attenuation, cosmic radiation and radiation belts.

The five major research areas listed in Subsection 3.7.5 and Item 6.4.2.2.1 were retained largely because of the perspective advantage from space that responds to the synoptic needs of these areas and the easy accessibility to interesting phenomena. Perspective advantage refers to the ability to detect and identify phenomena from a somewhat remote position. This advantage is pronounced in photointerpretation; many features can be seen and readily identified on aerial photos that cannot be detected by an expert on the ground. These advantages strongly outweigh the disadvantages.

The marginal area of fault movement monitoring (Item 6.4.2.3.2) was retained for the same general reason. The serious problem with this area is that of making sufficiently accurate spatial measurements from orbit.

The gravity field monitoring (Item 6.4.3.2.2) of smaller features was rejected because too many small features would be contributing data at the same time. Monitoring of continent-sized features was retained because the noise from local anomalies could be suppressed only from orbital altitude.

Magnetic field monitoring (Item 6.4.3.2.3) was rejected because of noise from the earth's radiation belts.

In summary, Table 3-49 lists 113 critical issues resulting from the organized overview analysis in Geology. Each issue was evaluated for applicability to research in space (either manned or automated spaceflight), as discussed in the several paragraphs above. As indicated in the thirteenth column, 65 critical issues were rejected.

3.7.5.2 Screening for Manned Space Research Applicability

The 48 critical issues that were found to be suitable for space research were screened next for applicability to manned space research programs.

Table 3-49 .

SCREENING OF CRITICAL ISSUES IN GEOLOGY

PROGRAM KEYS

A - NASA-MSC AIRCRAFT PROGRAM
B - MANNED MISSIONS (MERCURY, GEMINI, APOLLO)
C - ERTS
D - ERTS A&B
E - SKYLAB A
F - SKYLAB B

E - ESSENTIAL
H - HELPFUL
T - TOLERABLE
I - INTOLERABLE
N - NO EFFECT
U - UNKNOWN
NA - NOT APPLICABLE

		CRITICAL ISSUES	Program on which preliminary information has been developed	Program completely satisfying experimental requirements	Research requirements not satisfied by other programs	Critical issue is candidate for future manned space research
AGRICULTURE AND FORESTRY	6.4.1.1.1.1	How can specific rock/soil types be detected, identified, classified, and put to productive use?	A, B, C, D, E, F	NONE	✓	✓✓
WATER-OIL, GAS, STORAGE AND WASTE DISPOSAL	6.4.1.1.2.1	How can natural reservoirs, porous and permeable formations, and aquifers be detected and identified?	B, D, E, F	NONE	✓	✓✓
	6.4.1.1.2.2	How can areas of thick detrital fill be detected and evaluated?	B D E F	NONE	✓	✓✓
	6.4.1.1.2.3	How can the Earth's crust be used to store or condition waste products?	B D E F	NONE	✓	✓✓
HABITATION/ENGINEERING APPLICATIONS	6.4.1.1.3.1	How can present and future areas of interest be more effectively protected from geologic processes such as earthquakes, volcanic eruptions, landslides, erosion/transportation/deposition, and subsidence?	B C D E F	NONE	✓	✓✓
	6.4.1.1.3.2	How can dam sites for flood control and other controlling structures ever be identified?	B D E F	NONE	✓	✓✓
ENERGY	6.4.1.1.4.1	How can geothermal sources of energy (e.g., igneous, hydrothermal) be detected and identified?	E F	NONE	✓	✓✓
	6.4.1.1.4.2	How can geothermal sources of energy be predicted?				
MINERALS	6.4.1.1.5.1	How can areas of potential mineral deposits be located and identified?	A B C D E F	NONE	✓	✓✓
	6.4.1.1.5.2	How can potential source areas of petroleum and/or natural gas be located and identified?	A B C D E F	NONE	✓	✓✓
RECREATION	6.4.1.2.1.1	How can the location and proper construction of new park and recreational areas be significantly enhanced?				
EDUCATION	6.4.1.2.2.1	How can educational and scientific expeditions and field trips be aided by space observations and data?				
	6.4.1.2.2.3	How can the study of geologic processes and land forms be used to improve our understanding of submarine and subglacial features?				
	6.4.1.2.2.4	How can the motion of major ice flows be used to study the plastic flow of rock masses?				
	6.4.1.2.2.5	How can mutual data exchanges on cooperative and multiuser programs be coordinated?				
	6.4.1.2.2.6	What information can be exchanged in support of geologic mapping on a global scale?				
	6.4.1.2.2.7	What information can be exchanged in support of international geophysical programs?				
CRUST	6.4.2.1.1.1	Did the Earth's crust originate from a molten state?				
	6.4.2.1.1.2	Did the Earth's crust originate from gaseous condensation and the infall of planetesimal matter?				
CONTINENTS	6.4.2.1.2.1	Did the continents evolve from eruption of subcrustal material?				
	6.4.2.1.2.2	Did the continents evolve from the molten state?				
	6.4.2.1.2.3	How does the geosyncline affect continents?				
GEOMORPHOLOGY	6.4.2.1.3.1	Did the Earth's initial topography develop as a result of a shrinking Earth-expanding Earth?				
	6.4.2.1.3.2	Did the topography develop from eruptions of material from within the Earth?				
	6.4.2.1.3.3	Did the topography develop from tectonic forces?				
	6.4.2.1.3.4	Did the topography develop from erosion (ice, water, wind, etc.)?				
BIOTA	6.4.2.1.4.1	Did the Biota originate from spores from outer space?				
	6.4.2.1.4.2	Did the Biota originate from within the world ocean?				
	6.4.2.1.4.3	Did the Biota originate on land?				
STRUCTURE	6.4.2.2.1.1	Is the Earth a homogeneous accumulation of matter?	NONE	NONE	✓	✓✓
	6.4.2.2.1.2	Is the Earth a heterogeneous accumulation of matter?	NONE	NONE	✓	✓✓
	6.4.2.2.1.3	Is the Earth composed of readily identifiable masses?	NONE	NONE	✓	✓✓
	6.4.2.2.1.4	Is the Earth structure one of orderly and continuous concentric masses, containing but concentric masses, collisions, but not concentric masses?				
	6.4.2.2.1.5	What land forms can be related to dynamic processes?	B, D, E, F	NONE	✓	✓✓
	6.4.2.2.1.6	How can structures be identified by vegetation?	A	NONE	✓	✓✓
COMPOSITION	6.4.2.2.2.1	What chemical characteristics affect the physical nature of the Earth?				
	6.4.2.2.2.2	What chemicals contribute to pollution?				
CONFIGURATION	6.4.2.2.3.1	What is the shape of the Earth?	D E F	GEDS		
	6.4.2.2.3.2	What are the positions of land masses, polar ice sheets, and ocean basins?	B C D E F	NONE	✓	✓✓
	6.4.2.2.3.3	Are positions of land masses fixed or moving?				
	6.4.2.2.3.4	If moving, at what rate and direction?				
ACTIVITY	6.4.2.2.4.1	What regions of the crustal mass are experiencing isostatic readjustment?	ALL	NONE	✓	✓✓
	6.4.2.2.4.2	What tectonic and volcanic belts are active?	ALL		✓	✓✓
	6.4.2.2.4.3	What evidence is there that the continents are drifting?	B C D E F	NONE	✓	✓✓
	6.4.2.2.4.4	What evidence is there of sea floor spreading?	B C D E F	NONE	✓	✓✓
MOMENTUM	6.4.2.3.1.1.1	Is Earth spin constant or variable?				
	6.4.2.3.1.1.2	Is Earth revolution constant or variable?				
	6.4.2.3.1.1.3	What is the effect of precession of equinoxes on crustal processes?				
	6.4.2.3.1.1.4	What is the effect of lunar cycle on Earth tides?	A B D E	NONE	✓	✓✓
ENERGY	6.4.2.3.1.2.1	How does radiation transfer of energy affect the Earth's crust?				
	6.4.2.3.1.2.2	How does heat loss through volcanism affect the Earth's crust, through tectonic evolution?				
	6.4.2.3.1.2.3	How do crustal convection currents affect the energy change within the crust?				
	6.4.2.3.1.2.4	How does heat exchange at the Earth/sea boundary affect energy changes in the crust?				
	6.4.2.3.1.2.5	How do metamorphism and orogenic disintegration affect the energy changes within the crust?				
	6.4.2.3.1.2.6	How can the Curie point be observed?				
	6.4.2.3.1.2.7	How does the water/ice ratio affect the energy budget?	ALL	NONE	✓	✓
EROSION/DEPOSITION	6.4.2.3.1.3.1	How does erosion of mountain chains affect crustal stability?				
	6.4.2.3.1.3.2	How do the processes of erosion and deposition affect the crustal dynamics?				
	6.4.2.3.1.3.3	How does the Earth's rotation affect eroding agents?				
	6.4.2.3.1.3.4	How do sedimentary basins affect crustal stability?				
MASS	6.4.2.3.1.4.1	How does the principle of compensation of mass apply to the Earth's crust?				
	6.4.2.3.1.4.2	How do dynamic geologic processes affect the mass of the Earth?				
	6.4.2.3.1.4.3	How does planetesimal matter affect the mass of the Earth?				
	6.4.2.3.1.4.4	How do metamorphic processes affect mass changes within the crust?				
	6.4.2.3.1.4.5	How do crustal convection currents affect the mass distribution of the crust?				
PREDICTION	6.4.2.3.2.1.1	What knowledge and understanding of crustal dynamics, physics, and chemistry, are required for predicting the future state of the crust?				
	6.4.2.3.2.1.2	What is the rate of heat loss from the Earth's crust (in total)?	A, E, F	NONE	✓	✓✓
	6.4.2.3.2.1.3	What phenomena trigger widespread glacial activity? What are rates of change of mountain and continental glaciers?	ALL	NONE	✓	✓✓
	6.4.2.3.2.1.4	What is the rate of growth of the Earth's crust?				
	6.4.2.3.2.1.5	What is the relative rate of delta of the continents?	ALL	NONE	✓	✓✓
	6.4.2.3.2.1.6	What is the rate of compression/isostatic rebound of the Earth's crust?				
	6.4.2.3.2.1.7	What are the rates of relative movements of the Earth's major fault systems?	F	NONE	✓	✓✓
	6.4.2.3.2.1.8	What are the rates of sedimentation in major basin of deposition?	E F	NONE	✓	✓✓
	6.4.2.3.2.1.9	What are the rates of sea floor spreading?	E F	NONE	✓	✓✓
MODIFICATION	6.4.2.3.2.2.1	What are the physical characteristics of the Earth's crust and mantle?	ALL	NONE	✓	✓✓
	6.4.2.3.2.2.2	What are the rates of crustal warping, positive and negative?				
	6.4.2.3.2.2.3	What are the rates of flow of the major river systems?	ALL	NONE	✓	✓✓
	6.4.2.3.2.2.4	What geological features could be modified to serve the needs of man?	ALL	NONE	✓	✓✓
	6.4.2.3.2.2.5	How could select geologic features be modified to serve man better?	ALL	NONE	✓	✓✓
	6.4.2.3.2.2.6	How could some geologic processes be augmented, dissipated or controlled for the betterment of mankind?	ALL	NONE	✓	✓✓
SHORT RANGE	6.4.3.1.1.1	What causes glaciation?	ALL	NONE	✓	✓✓
	6.4.3.1.1.2	Are we entering interglacial epoch or is the glacial cycle completed?	ALL	NONE	✓	✓✓
EXTENDED RANGE	6.4.3.1.2.1	How do ocean basins, continental masses control weather?	ALL	NONE	✓	✓✓
	6.4.3.1.2.2	How does the radiant temperature of the Earth contribute to the control of weather?	ALL	NONE	✓	✓✓
CLIMATE	6.4.3.1.3.1	How do mountain chains affect local and regional climates?	ALL	NONE	✓	✓✓
	6.4.3.1.3.2	How do plains provinces affect local and regional climates?	ALL	NONE	✓	✓✓
	6.4.3.1.3.3	How do large geothermal anomalies affect local climates?	ALL	NONE	✓	✓✓
	6.4.3.1.3.4	How do large population centers affect climate?	ALL	NONE	✓	✓✓
	6.4.3.1.3.5	How long has the Earth possessed seasonal weather variations?				
GRAVITATION	6.4.3.2.2.1	How do drifting continents affect the Earth's gravity field?				
	6.4.3.2.2.2	How do erosion, transportation and deposition of sediments at large coastal delta development affect Earth's gravity gradients?				
	6.4.3.2.2.3	How do continental size features affect the Earth's gravity fields?				
	6.4.3.2.2.4	How do mountain roots affect the Earth's gravity field?				
	6.4.3.2.2.5	How do areas of concentration of minerals (metallics-nonmetallics) affect gravity gradients?				
	6.4.3.2.2.6	How do large scale structures, i.e., salt domes, major folds, etc., affect the Earth's gravity gradients?				
	6.4.3.2.2.7	How does plastic flow (convection currents) affect the Earth's gravity field?				
ELECTROMAGNETIC	6.4.3.2.3.1	How do major crustal lineaments affect the electromagnetic field?				
	6.4.3.2.3.2	How does the subcrustal plastic flow of rock masses affect the electromagnetic field?				
	6.4.3.2.3.3	How do drifting continents affect the electromagnetic field?				
	6.4.3.2.3.4	How do areas of concentration of minerals (metals) affect the electromagnetic field?				
	6.4.3.2.3.5	How do continental size features affect the Earth's electromagnetic field?				
MICRO ORGANISMS	6.4.3.3.1.1	What effects would large scale volcanic eruptions have on Micro Organisms?				
	6.4.3.3.1.2	What effects would increased glacial activity have on Micro Organisms?				
	6.4.3.3.1.3	What are the effects of migrating magnetic poles on Micro Organisms?				
	6.4.3.3.1.4	What are the effects of migrating geographic poles on Micro Organisms?				
MACRO ORGANISMS	6.4.3.3.2.1	What effects would large scale volcanic eruptions have on Macro Organisms?				
	6.4.3.3.2.2	What effects would increased glacial activity have on Macro Organisms?				
	6.4.3.3.2.3	What are the effects of migrating magnetic poles on Macro Organisms?				
	6.4.3.3.2.4	What are the effects of migrating geographic poles on Macro Organisms?				
PLANTS	6.4.3.3.3.1	What effects would large scale volcanic eruptions have on plants?	ALL	NONE	✓	✓✓
	6.4.3.3.3.2	What effects would increased glacial activity have on plants?	ALL	NONE	✓	✓✓
	6.4.3.3.3.3	What are the effects of migrating magnetic poles on plants?				
	6.4.3.3.3.4	What are the effects of migrating geographic poles on plants?				

FOLDOUT FRAME

FOLDOUT FRAME 2

The effects of the following factors were considered with regard to the retention of individual remaining research areas:

Person/Factor	Capability/Limitation
Scientist-Observer	Real-time data analysis and evaluation
	Multiple sensor use
	Sensor mode and parameter selection
	Cooperation with ground. Principal investigator on ground
Development Engineer	Target selection
	Sensor operation and parameter variation
	Evaluation of sensor design and performance
	Component qualification testing
Technician	Equipment setup, checkout, maintenance, and calibration
	Servicing of sensor and equipment consumables
Human Safety Factors	Environmental extremes (external) (radiation, temperature, and vacuum)
	Exceeding physiological limits (weightlessness, fatigue, dehydration)
	Excessive physiological stress (such as sensory deprivation)
	Miscellaneous (high voltage, noise level, flammables)
Mission Performance Degradation	Acceleration disturbances (attitude control and crew mobility)
	Effluent release (environmental contamination)
	Repetitive duty cycles (continuous, high-precision observations)

Forty-three critical issues were retained after applying these screening factors. The overriding reason for their retention was the learning process required to fulfill the requirements of the research areas.

Only the onboard scientist can identify the phenomena associated with highly esoteric subjects and point an instrument at them with a high degree of confidence. The undesirable influences of having man on board can be reduced by design consideration and were outweighed by the advantages of having human skill available at the scene of the data sensing. The exception to this was the remainder of the gravity field research area. It appeared that man was too deleterious for that area to be retained on a manned mission.

The fault system monitoring (Item 6.4.2.3.2) was not greatly influenced by this screening. Analogous data are now taken from aircraft without undue stability problems. The techniques are also standard and pose no threat to man.

3.7.5.3 Accounting for Contributions of Ongoing Programs

The final screening to which the major research areas were subjected related to ongoing programs. Where the information requirements of a research area are expected to be met by other programs, this was noted in Table 3-49, and those critical issues needing program support were treated further. The following major programs were considered: NASA's aircraft program, Mercury, Gemini, Apollo, EROS, ERTS, Skylab A, and Skylab B.

Of special interest under the NASA aircraft program are the projects listed in Table 3-50. NASA's aircraft program has a wide variety of sensors, so that valuable data are being gathered throughout the useful area of the electromagnetic spectrum. The value of the data is reduced somewhat by lack of spatial correspondence occasioned by the several sensor designs. Considerable advancement is being made, however, in the techniques for using the data. Table 3-50 shows projects of importance in the area of data analysis. Valuable as they are, these projects are only a beginning in the process of learning how to use remote-sensing data most effectively. It is interesting to note that these programs have a strong tendency to concentrate on imagery. Understanding the geologic phenomena in terms of imagery generated by returns from various portions of the spectrum seems to be a natural evolutionary process. The use of photointerpretation as a control on multispectral analysis developments (Subsection 3.7.5) appears to be a technique that is already developing. The importance of actually recognizing this trend is related to image geometrical correspondence. Such correspondence is important in relating the nonvisible return to the natural, familiar domain of the photointerpreter.

TABLE 3-50

SELECTED NASA AIRBORNE GEOLOGY-RELATED RESEARCH

Investigator	Study Task	Synopsis
H. Smedes USGS	Automatic mapping and data enhancement techniques, Yellowstone National Park, Wyoming	Geologic features from radar, special pattern recognition, used 3 scanners (0.4 to 14 microns). 11 categories mapped to 80% accuracy.
L. R. Page USGS	Geologic analysis of the X-band radar mosaic of Massachusetts	
L. C. Rowan USGS	Remote sensing reconnaissance at Mill Creek Area, Arbuckle Mountains, Oklahoma	IR image interpretation, Tishomingo Anticline, relatively pure rock differentiated (8 to 14 microns), certain time of day to get certain results (morning or afternoon sun related to linear feature trends).
H. L. Berryhill USGS	Results of remote-sensing studies along the south Texas coast	Dynamics of sediment movement, color imagery, color IR, IR.
F. Canney USGS-Maine	Remote detection of geochemical soil anomalies, Catheart Mountain, Maine	Analysis of reflectance spectra (0.35 to 1.1) of balsam fir and red spruce. Significant difference in trees growing over a copper-molybdenum deposit.
M. Clark USGS-Palo Alto	Geologic utility of small-scale air photographs	Large-scale relationships emphasized. Several scales of value varying by successive factors of three.
H. MacDonald University of Kansas	The influence of radar look direction on the detection of selected geological features	Fault and lineament detection. look-direction relative to feature trend important.
G. W. Green USGS	Aerial infrared surveys and borehole temperature measurements of coal mine fires in Pennsylvania.	
I. A. Klinc Stanford University	Airborne in spectral study of volcanic and plutonic rocks, Sonora Pass test site.	IR emission spectra (6.2 to 13.33 microns), volcanic rocks (basalts, andesites), plutonic rock (quartz mozonite porphyry) identified (90% or better).

In summary, this program is valuable by virtue of (1) data gathered in a wide spectral range, and (2) techniques developed for use of multispectral data. The program contributes to the research areas but it does not satisfy any area by a substantial margin.

Manned missions, including the Mercury, Gemini, and Apollo programs, are notable as sources of data. These data are essentially in the form of visible-range imagery, and are considered valuable because of the various altitudes at which the data were taken.

The EROS program was oriented toward unmanned earth resource surveys. Largely superseded by the ERTS program (the two acronyms now being considered as relating to the same program), the EROS effort had value in that considerable planning and priority-fixing occurred with relation to geologic development.

The ERTS program will be the first program dedicated to solving earth-resource survey problems. It is regarded as an interim step; however, it is one that will contribute to the workable solution. From the standpoint of total solution, ERTS is spectrally limited; and because it is unmanned, it will have a limited experimentation repertoire. This is a serious limitation when the entire problem is considered, although it is a significant and essential step forward. ERTS is expected to make across-the-board contributions to the data supply, data-reduction techniques, operational considerations, and related requirements. It is not considered that ERTS will completely answer the knowledge requirements of any of the research areas.

Skylab A will expand the knowledge obtainable in the spectral area, inasmuch as thermal infrared sensors are planned. An advance in metric quality of results will also occur because of the inclusion of metric cameras. The additional capability provided by manned operation will be explored in these facilities, which are considered here as failing to provide the total information required for the research areas in only the following respects:

A. The instrumentation probably will not yet be related to a single baseline design so that all phenomena derived from information in different portions of the EM spectrum can be automatically carried onto a map generated with the aid of the visible-range sensor. Instrumentation may also be too limited.

B. The scope of the experimental effort in the Skylab program will probably be insufficient. Longer experiment times, larger numbers of onboard operations, use of scientists in the spacecraft, and better onboard experimentation facilities are considered essential in advancing the geological surveys to a reasonable potential.

The contributions of each of the programs listed above are valuable in meeting the information requirements of the several geology research areas. This is especially so when it is remembered that basic geologic understanding itself must be increased in some instances; for example, in areas closely associated with massive crustal instability. This category includes such things as volcanic activity and earthquakes. When considered in this light, a series of programs, each contributing data that the geologists can use for their own esoteric purposes, is more likely to bring about a favorable overall result than a single mammoth large-scale program that might be planned now. With multiple programs, it will be possible to plan and modify future activities in the light of new knowledge from current efforts. In aggregate, the ongoing programs are expected to provide partial answers to all of the geologic research areas.

The issues passing these criteria are denoted by a check in Column 34 of Table 3-49. The critical issue rejected (6.4.2.2.3.1) can be satisfied by the ongoing Geodetic Satellite Program (GEOS). The areas surviving the space-application, the manned, and the ongoing program screenings are summarized as follows:

A. Five Major research areas:

1. Identification of rock and soil types.
2. Discovery of mineral and oil deposits
3. Use of the earth's crust to store or condition commodities or waste.
4. Avoidance of geologic disasters.
5. Utilization of geothermal energy sources.

B. Two supporting research areas:

1. Identification of land forms associated with dynamic processes.
2. Identification of structural forms from associated vegetation.

C. One marginal research area - Monitoring of relative movements of major fault systems.

3.7.5.4 Grouping of Critical Issues by Experimental Approach

The critical issues were grouped into research clusters, generally on the basis of similarity of experimental approach or commonality of measurement requirements. However, the gulf between current geologic knowledge and the geologic critical issues, particularly in the case of those relating to crustal instability, made the grouping process difficult. Therefore, the grouping of the geologic critical issues also reflected the information content and conceptual similarity. There is, however, an overall harmony of experimental approach, not only among geologic critical issues but among the research areas. For example, all rely on the perspective advantage: all are predicted on the use of surrogates (to relieve the spatial resolution problem among other things); all address a comprehensive understanding of the areas as a common denominator; all need angular correlation of multispectral data at the source so that signature analysis and automatic mapping of derived phenomena may occur; and all are expected to foster the use of photointerpretive techniques.

The clusters formed on the basis of these considerations are identified and briefly summarized below.

A. Rock and Soil Type Identification
B. Use of Earth's Crust to Store and Condition Commodities and Waste
C. Geologic Disaster Avoidance
D. Utilization of Geothermal Energy Sources
E. Mineral and Oil Deposit Discovery
F. Identification of Land Forms and Structural Forms

3.7.5.5 Brief Descriptions of the Research Clusters

In summary, in the subdiscipline of Geology, six research clusters were formed from the 42 critical issues judged to be suitable for a manned earth orbital research program. A brief description of these research clusters is presented at the end of Subsection 3.7. More detailed descriptions may be found in Appendix C.

3.7.6 Screening and Grouping of Critical Issues in Hydrology

The critical issues identified in the organized overview analysis of Hydrology, as discussed in Subsection 3.7.1.1, were examined to determine which would be candidates for further consideration for manned earth orbital experiment programs. These critical issues resulted from the study of objectives of this discipline to achieve (1) better utilization of the water resources of the Earth, and (2) better understanding of the elements of the hydrologic cycle.

Application areas (areas in which research is required) to permit better utilization of water resources are:

- A. Water management and flood control
- B. Inventory of surface and subsurface water.
- C. Topographic information, as it relates to the hydrologic features of river basins, lakes, rivers, and reservoirs.
- D. Circulation in large bodies of water.
- E. Water pollution.

To increase the understanding of elements of the hydrologic cycle, and to increase understanding to permit better prediction of the water resources of the earth, the application areas are:

- A. Determination of the water budget, consisting of:
  1. Water in the form of atmospheric vapor.
  2. Water in the form of precipitation.
  3. Water in the solid state (snow and ice).
  4. Soil moisture.
  5. Surface and subsurface water.
- B. Determination of boundary layer effects relating to the earth's energy budget:
  1. Measurement of the thermal flux transferred from the surface of the earth into the atmosphere.
  2. Measurement of the horizontal vapor flux distribution on the earth.

3.7.6.1 Screening of Critical Issues for Applicability to Research in Space

The criteria used to determine the suitability of a critical issue for research in space have been previously discussed in Subsection 3.7.1.2, and are tabulated in Table 3-51, which summarizes the screening process in Hydrology.

Considering the application area of water management and flood control, the research objectives require data to be obtained on storm-flow concentration by photography (or photographic imagery) from orbit; the collection of data from ground sensors (stream-flow gages); determination of the areal extent of precipitation from storms (by microwave instrumentation); and determination of runoff from snowpack, which can be accomplished by measurement of surface temperature from orbit and surface water flow by ground sensors, in conjunction with metoerological data. The primary criteria determining the applicability of space research are (1) the advantage of orbital altitude for line-of-sight data collection; (2) wide geographical coverage, for both data collection and photography; and (3) target selection and repeatable ground track, particularly in the case of storm and flooding conditions in localized areas. The balance of the orbital criteria are not significant, nor are the criteria relating to the space environment. The critical issues of this application area are therefore considered suitable for research in space.

Under the application area of surface and subsurface water inventory, observations can be accomplished by the use of imaging sensors (photographic, infrared, or microwave) to determine the areal extent of surface water bodies and snow and ice cover. Underground water sources can be identified at the point of discharge into surface water by infrared radiometry, and soil moisture (to a limited depth) can be identified by passive microwave instrumentation. The primary orbital characteristics of value are high altitude and target selection (to obtain sightings through scattered cloud cover). Again the balance of the orbital criteria and the characteristics of the space environment are not significant, and all of these critical issues are suitable for research in space.

FOLDOUT FRAME 1

Table 3-51

SCREENING OF CRITICAL ISSUES IN HYDROLOGY

PROGRAM KEYS

A = ERTS A & B
B = NATIONAL OPERATIONAL METEOROLOGICAL SATELLITE SYSTEM (NOMSS)
C = NASA-MSC AIRCRAFT PROGRAM
D = MANNED MISSIONS (GEMINI, APOLLO, SKYLAB)

DEFINITION OF SYMBOLS

E = ESSENTIAL
H = HELPFUL
N = NO EFFECT
T = TOLERABLE
I = INTOLERABLE
U = EFFECTS UNKNOWN
NA = NOT APPLICABLE

Column groups: SPACE RESEARCH SELECTION CRITERIA (ORBITAL CHARACTERISTICS: columns 5–10; SPACE ENVIRONMENT CHARACTERISTICS: columns 11–16); MANNED SPACE RESEARCH SELECTION CRITERIA (PARTICIPATION OF MAN: SCIENTIST/OBSERVER, DEVELOPMENT ENGINEER, TECHNICIAN; FLIGHT SAFETY; MISSION PERFORMANCE DEGRADATION); RELATION TO OTHER PROGRAMS.

Area	Subject	No.	Critical Issues	Orbital Altitudes	Wide Areal (Geographic) Coverage	Target Selection	Repeatable Ground Track	Orbital Velocity/Altitude (V/H) Ratio	Relative Velocity	Gravitational Effects	Atmosphere (Vacuum)	Meteoroids	Atmospheric Attenuation	Cosmic Radiation	Radiation Belts	Critical Issue is Suitable for Space Research (✓)	Real Time Data Analysis and Evaluation	Multiple Sensor Use	Sensor Mode and Parameter Selection	Cooperation with Principal Investigator on the Ground	Target Selection	Sensor Operation and Parameter Variation	Evaluation of Sensor Design and Performance	Component Qualification Testing	Equipment Setup, Checkout, Maintenance, and Calibration	Servicing of Sensor & Equipment Consumables	External Environmental Extremes (Radiation, Temperature, Vacuum, etc.)	Exceeds Physiological Limits (G-Light, Life Support, etc.)	Excessive Psychological Stress (Sensory Deprivation, etc.)	Affects Crew Safety (High Voltage, Noise Level, Flammables, etc.)	Acceleration Disturbances (Attitude Control, Crew Motion, etc.)	Effluent Release (Environmental Contamination)	Repetitive Duty Cycles (Continuous High Precision Operation)	Critical Issue is Suitable for Manned Space Research (✓)	Program on Which Preliminary Information Has Been Developed	Program Completely Satisfying Experiment Requirements	Research Requirements Not Satisfied by Other Programs (✓)	Critical Issue is Candidate for Future Manned Space Research (✓✓)
UTILIZATION – KNOWLEDGE	WATER MANAGEMENT AND FLOOD CONTROL	6.5.1.1.1.1	What synoptic data is required for flood forecasting and water-resource systems management?	H	E	H	H	T	N	N	N	T	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	T	NA	NA	NA	I	I	NA	✓	A, B	NONE	✓	✓✓
		6.5.1.1.1.2	How can reliable information on the concentration of storm flows be obtained?	E	E	H	H	T	N	N	N	N	I	T	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	I	NA	✓	B	NONE	✓	✓✓
		6.5.1.1.1.3	How can real-time communication of ground-based hydrologic data be accomplished?	E	E	H	H	T	N	N	N	N	T	N	N	✓	H	NA	NA	H	NA	NA	NA	NA	NA	NA	T	NA	NA	NA	I	I	NA	✓	A, B	NONE	✓	✓✓
		6.5.1.1.1.5	What is the level and movement of groundwater?	H	E	E	E	T	N	N	N	N	T	N	N	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	I	NA	✓	A, C, D	NONE	✓	✓✓
		6.5.1.1.1.6	What is the areal extent of precipitation?	E	E	H	H	T	N	N	N	T	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	I	NA	✓	B	NONE	✓	✓✓
		6.5.1.1.1.7	How can the runoff from snowpack be predicted?	H	E	H	H	T	N	N	N	T	T	T	I	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	I	NA	✓	A, B	NONE	✓	✓✓
	SURFACE AND SUBSURFACE WATER INVENTORY	6.5.1.1.2.1	How can a synoptic inventory of the surface area and geographic location of the world's major lakes and reservoirs be obtained?	H	E	H	H	T	N	N	N	T	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	T	NA	NA	NA	I	I	NA	✓	NONE	NONE	✓	✓✓
		6.5.1.1.2.2	How can a synoptic inventory of the world's snow and ice cover be obtained on a perennial and annual basis?	E	E	H	H	T	N	N	N	T	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	T	NA	NA	NA	I	T	NA	✓	A	NONE	✓	✓✓
		6.5.1.1.2.3	What is the area extent and albedo of snowpacks and the lower limits of snowlines?	H	E	H	H	T	N	N	N	T	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	I	NA	✓	B	NONE	✓	✓✓
		6.5.1.1.2.4	What is the areal extent of ice in estuaries, rivers, and lakes, and glaciers?	H	E	H	H	T	N	N	N	T	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	T	NA	✓	B	NONE	✓	✓✓
		6.5.1.1.2.5	How can the location and extent of underground water sources be identified?	H	E	H	H	T	N	N	N	T	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	T	NA	✓	C	NONE	✓	✓✓
		6.5.1.1.2.6	How can soil moisture be measured?	H	H	H	H	T	N	N	N	I	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	I	NA	✓	C	NONE	✓	✓✓
		6.5.1.1.2.7	What is the depth and water content of snow?	H	H	H	H	T	N	N	N	T	T	I	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	T	NA	✓	NONE	NONE	✓	✓✓
		6.5.1.1.2.8	What is the location of large leakage which can be used as of fresh water?	H	E	H	H	T	N	N	N	T	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	I	NA	✓	NONE	NONE	✓	✓✓
	TOPOGRAPHY	6.5.1.1.3.1	What is the topography, geologic structure, and soil cover in underdeveloped regions of the world?	H	E	H	H	I	N	N	N	T	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	T	NA	NA	NA	I	T	NA	✓	D	NONE	✓	✓✓
		6.5.1.1.3.2	What are the hydrologic features of coastal regions and large inland lakes?	H	E	H	H	T	N	N	N	T	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	T	NA	NA	NA	I	T	NA	✓	D	NONE	✓	✓✓
		6.5.1.1.3.3	What are the geomorphological characteristics of river basins?	H	E	H	H	T	N	N	N	T	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	I	NA	✓	D	NONE	✓	✓✓
		6.5.1.1.3.4	How can the best routing for canals and artificial waterways be determined?	H	E	H	H	T	N	N	N	T	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	I	NA	✓	D	NONE	✓	✓✓
UTILIZATION – EFFECTS	LAND USE	6.5.1.2.1.1	How can land-use mapping and classification be improved?	H	E	H	H	T	N	N	N	T	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	T	NA	NA	NA	I	T	NA	✓	D	NONE	✓	✓✓
		6.5.1.2.1.2	What is the extent of diversion of water for user requirements?	H	E	H	H	T	N	N	N	I	T	I	I	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	T	NA	✓	A, C, D	NONE	✓	✓✓
		6.5.1.2.1.3	What is the extent of the loss of water along irrigation canals?	H	E	H	E	T	N	N	N	T	T	I	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	I	NA	✓	A, C, D	NONE	✓	✓✓
		6.5.1.2.1.4	What are the effects of changes in vegetation patterns on the run-off of precipitation?	H	E	H	E	T	N	N	N	I	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	T	NA	✓	A, D	NONE	✓	✓✓
		6.5.1.2.1.5	What are the location where excessive irrigation is increasing the saline content of soil?	H	E	H	E	T	N	N	N	T	T	I	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	I	NA	✓	A, D	NONE	✓	✓✓
	WATER CIRCULATION	6.5.1.2.2.1	What are the water circulation patterns in coastal waters, estuaries, and large lakes?	H	E	H	H	T	N	N	N	T	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	I	NA	✓	D	NONE	✓	✓✓
		6.5.1.2.2.2	What are the effects of currents and tidal flows upon harbors and estuaries?	H	E	H	H	T	N	N	N	T	I	T	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	I	NA	✓	D	NONE	✓	✓✓
	WATER POLLUTION	6.5.1.2.3.2	What are the effects of streamflow and wastes upon coastal waters?	H	H	H	H	T	N	N	N	T	I	I	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	T	NA	✓			✓	✓✓
		6.5.1.2.3.3	What is the extent of saline intrusion in estuaries?	H	H	H	H	T	N	N	N	T	I	T	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	I	NA	✓	C	NONE	✓	✓✓
		6.5.1.2.3.4	What is the dispersion of visible pollutants in coastal waters, estuaries, large lakes, and reservoirs?	H	H	H	H	T	N	N	N	I	T	I	I	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	I	NA	✓	C, D	NONE	✓	✓✓
		6.5.1.2.3.5	How can the occurrence and extent of algal blooms be determined?	H	H	H	H	T	N	N	N	T	T	I	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	I	NA	✓	C	NONE	✓	✓✓
		6.5.1.2.3.6	How can oil slicks on the surface of the ocean be identified?	H	E	H	H	T	N	N	N	T	T	T	I	✓	H	H	H	H	H	H	H	NA	H	E	T	NA	NA	NA	I	I	NA	✓	C	NONE	✓	✓✓
		6.5.1.2.3.8	How can the transportation and deposition of sediment be determined?	H	E	H	H	T	N	N	N	I	T	I	I	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	I	NA	✓	A, C, D	NONE	✓	✓✓
SCIENTIFIC UNDERSTANDING – SCIENTIFIC KNOWLEDGE – WATER BUDGET	WATER VAPOR	6.5.2.1.1.1.1	How can the amount of precipitable water within the Earth's atmosphere be determined?	E	E	N	H	T	N	N	N	I	I	I	I	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	I	NA	✓	B	NONE	✓	✓✓
		6.5.2.1.1.1.2	What are the temporal variations in the fluxes of water vapor into and out of large drainage basins and lakes, and continental areas?	E	E	H	H	T	N	N	N	I	I	T	T	✓	H	H	H	H	H	H	H	NA	H	NA	I	NA	NA	NA	I	I	NA	✓	B	NONE	✓	✓✓
		6.5.2.1.1.1.3	How can the water vapor content within the atmosphere at the atmosphere-surface interface be determined?	E	E	H	H	T	N	N	N	T	T	I	T	✓	H	H	H	H	H	H	H	NA	H	NA	I	NA	NA	NA	I	I	NA	✓	B	NONE	✓	✓✓
		6.5.2.1.1.1.4	How can the occurrence and horizontal and vertical flow of water vapor over large areas be determined?	E	E	H	H	T	N	N	N	T	T	I	I	✓	H	H	H	H	H	H	H	NA	H	NA	I	NA	NA	NA	I	I	NA	✓	B	NONE	✓	✓✓
	PRECIPITATION	6.5.2.1.1.2.1	How can the global distribution of precipitation be determined on a synoptic basis?	E	E	N	H	I	N	N	N	T	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	T	NA	NA	NA	I	T	NA	✓	B	NONE	✓	✓✓
		6.5.2.1.1.2.2	How can long-range prediction of precipitation (rain and snow) be improved?	E	E	H	E	T	N	N	N	T	T	I	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	I	NA	✓	B	NONE	✓	✓✓
	EVAPOTRANSPIRATION	6.5.2.1.1.3.1	How can reliable information on evaporation of water from the land and ocean be obtained?	E	E	H	E	T	N	N	N	I	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	I	NA	✓	B	NONE	✓	✓✓
		6.5.2.1.1.3.2	What are the evaporation and evapotranspiration losses along major river systems in arid environments?	H	E	H	E	T	N	N	N	T	I	T	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	I	NA	✓	B	NONE	✓	✓✓
	SNOW AND ICE	6.5.2.1.1.4.1.1	How can the areal extent of snow cover be determined?	H	E	H	H	T	N	N	N	T	T	I	I	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	T	NA	✓	C	NONE	✓	✓✓
		6.5.2.1.1.4.1.2	How can snow depth and moisture content be determined?	H	E	H	H	T	N	N	N	T	T	T	I	✓	H	H	H	H	H	H	H	NA	H	E	T	NA	NA	NA	I	I	NA	✓	C	NONE	✓	✓✓
		6.5.2.1.1.4.1.3	How can free water appearing on the snow surface be sensed?	H	E	H	H	T	N	N	N	T	T	T	I	✓	H	H	H	H	H	H	H	NA	H	E	T	NA	NA	NA	I	I	NA	✓	C	NONE	✓	✓✓
		6.5.2.1.1.4.1.4	How is the apparent temperature of snow in the microwave region affected by density, depth, liquid water content, and sensible temperature?	H	E	H	H	T	N	N	N	T	T	I	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	I	NA	✓	C	NONE	✓	✓✓
		6.5.2.1.1.4.2.1	What is the distribution of lake ice?	H	H	H	H	T	N	N	N	T	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	T	NA	NA	NA	I	T	NA	✓	B	NONE	✓	✓✓
		6.5.2.1.1.4.2.2	How can the thickness, temperature, and albedo of ice be determined?	H	H	H	H	T	N	N	N	I	I	T	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	I	NA	✓	A, B, C, D	NONE	✓	✓✓
		6.5.2.1.1.4.3.1	How is sea ice movement related to climatic and ocean current patterns?	H	E	H	E	T	N	N	N	T	T	I	T	✓	H	H	H	H	H	H	H	NA	H	E	T	NA	NA	NA	I	T	NA	✓	A, B, C, D	NONE	✓	✓✓
		6.5.2.1.1.4.3.2	How can anomalies in the sea ice pack be related to climatic or subsurface causes?	H	H	H	H	I	N	N	N	T	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	I	NA	✓			✓	✓✓
		6.5.2.1.1.4.4.1	How can the areal extent of glacial ice be determined?	H	E	H	H	T	N	N	N	I	I	T	T	✓	H	H	H	H	H	H	H	NA	H	E	T	NA	NA	NA	T	I	NA	✓	B	NONE	✓	✓✓
		6.5.2.1.1.4.4.2	How can the volume of glacial ice be determined?	H	E	H	H	I	N	N	N	T	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	T	I	NA	✓	A, B, C, D	NONE	✓	✓✓
	SOIL MOISTURE	6.5.2.1.1.5.2	What is the global distribution of soil moisture?	E	E	H	H	I	N	N	N	T	I	I	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	T	NA	✓	C	NONE	✓	✓✓
	SURFACE AND SUBSURFACE WATER	6.5.2.1.1.6.1	How can the water content of lakes and be determined?	H	E	H	H	I	N	N	N	I	I	I	I	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	I	I	NA	✓	B	NONE	✓	✓✓
SCIENTIFIC UNDERSTANDING – ENERGY BUDGET	SOLAR RADIATION	6.5.2.1.2.1.1	What is the global distribution of solar irradiance?	E	E	N	H	T	N	N	N	T	T	T	T	✓	H	H	H	H	N	H	H	NA	H	N	T	NA	NA	NA	I	I	NA		B			
		6.5.2.1.2.1.2	What is the global distribution of solar energy reflected from the clouds and surface of the Earth?	E	E	N	H	T	N	N	N	T	T	T	T	✓	H	H	H	H	N	H	H	NA	H	N	I	NA	NA	NA	I	I	NA		B			
	TERRESTRIAL THERMAL RADIATION	6.5.2.1.2.2.1	What is the global distribution of the infrared radiance of the Earth's surface?	E	E	N	H	I	N	N	N	T	T	T	T	✓	H	H	H	H	N	H	H	NA	H	N	I	NA	NA	NA	I	I	NA	✓	B	NONE	✓	✓✓
		6.5.2.1.2.2.2	What is the diurnal variation in the heat flux of thermal reservoirs beneath the surface of the Earth?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.5.2.1.2.2.3	How can the diurnal variations in temperature of the surface of the Earth be determined?	E	E	N	H	T	N	N	N	T	T	T	T	✓	H	H	H	H	N	H	H	NA	H	N	I	NA	NA	NA	I	I	NA	✓	B	NONE	✓	✓✓
	ATMOSPHERE-SURFACE LAYERS BOUNDARY	6.5.2.1.2.3.1	What are the characteristics of the boundary layer at the interface between the atmosphere and the Earth's surface?	E	E	N	H	T	N	N	N	T	T	T	T	✓	H	H	H	H	N	H	H	NA	H	E	T	NA	NA	NA	I	I	NA	✓	B	NONE	✓	✓✓
		6.5.2.1.2.3.2	What is the rate of flow of thermal flux from the Earth into the turbulent atmosphere?	E	E	N	H	T	N	N	N	T	I	T	T	✓	H	H	H	H	N	H	H	NA	H	E	I	NA	NA	NA	T	I	NA	✓	B	NONE	✓	✓✓
		6.5.2.1.2.3.3	What is the distribution of the horizontal vapor flux over the surface of the Earth?	E	E	N	H	I	N	N	N	I	T	T	T	✓	H	H	H	H	N	H	H	NA	H	NA	I	NA	NA	NA	I	I	NA	✓	B	NONE	✓	✓✓
	ATMOSPHERIC POLLUTION	6.5.2.1.2.4.1	What are the effects of dust and contaminants in the Earth's atmosphere upon the energy budget?	E	E	H	E	T	N	E	N	T	E	T	T	✓	H	H	H	H	E	H	H	H	H	H	I	NA	NA	NA	I	T	NA	✓	NONE	NONE	✓	✓✓
		6.5.2.1.2.4.2	What are the effects of air pollution upon the climate of urban areas?	E	E	H	E	T	N	E	N	T	E	T	T	✓	H	H	H	H	E	H	H	H	H	H	I	NA	NA	NA	I	I	NA	✓	NONE	NONE	✓	✓✓
	LAND USE	6.5.2.1.2.5.1	How can seasonal changes in vegetation cover be determined?	E	E	N	H	T	N	N	N	T	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	T	T	NA		C	A		
		6.5.2.1.2.5.2	What are effects of seasonal changes in vegetative cover upon regional energy balance?	E	E	N	H	T	N	N	N	T	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	T	NA	NA	NA	T	T	NA		C	A		
		6.5.2.1.2.5.3	What are the regional effects of changes in land use of the climate?	H	E	H	E	T	N	N	N	T	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	I	NA	NA	NA	T	I	NA	✓	D	NONE	✓	✓✓
		6.5.2.1.2.5.4	Can the characteristics of sand dunes be used to predict the climate in arid regions?	H	E	H	E	T	N	N	N	T	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	T	NA	NA	NA	T	I	NA	✓	D	NONE	✓	✓✓
UNDERSTANDING OF EFFECTS	GEOGRAPHY	6.5.2.2.1.1	What is the effect of cultural changes of the surface of the Earth on the elements of the hydrologic cycle?	H	E	H	E	T	N	N	N	T	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	T	NA	NA	NA	T	T	NA	✓	D	NONE	✓	✓✓
		6.5.2.2.1.2	How is the watershed affected by changes in use of land?	H	E	H	E	T	N	N	N	T	T	T	T	✓	H	H	H	H	H	H	H	NA	H	E	T	NA	NA	NA	T	T	NA	✓	D	NONE	✓	✓✓
	ATMOSPHERIC POLLUTION	6.5.2.2.2.1	What are the effects of contaminants in the atmosphere on the elements of the hydrologic cycle?	E	E	N	E	T	N	E	N	T	E	T	T	✓	H	H	H	H	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	✓	NONE	NONE	✓	✓✓
	WEATHER MODIFICATION	6.5.2.2.3.1	What is the effect of cloud seeding experiments on elements of the hydrologic cycle?	E	E	E	E	I	N	N	N	T	E	T	T	✓	E	H	H	E	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	✓	C, D	NONE	✓	✓✓

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FOLDOUT FRAME 2

To obtain topographic information, primary reliance will be placed on photography using metric cameras. From the high altitude of orbit, terrain relief can be determined by using stereo photography with a resolution of the order of 300 feet; in areas of relatively flat terrain, the topography will be inferred by photographic interpretation. Photographic data will be supplemented by infrared imagery (under eclipse conditions) and by radar imagery (to penetrate cloud cover). The primary advantage of space is the wide geographical coverage obtained from orbit, with target selection and the capability of repetitive ground tracking being secondary. The balance of the orbital criteria and the space-environmental criteria are again unimportant.

The application area of water circulation will employ photography to identify visible circulation patterns as well as bottom topography in shallow waters (accomplished in Gemini photography), and thermal infrared imagery can be used to identify discharge of fresh water into the ocean by identification of thermal gradients. The previously discussed orbital characteristics apply, and this research objective is suitable for research in space.

In the area of water pollution, saline intrusion in estuaries may be detected by thermal infrared imagery, and visible pollutants will be apparent in photographic records. Algal blooms become quite apparent by the use of false-color infrared Ektachrome. The detection of oil slicks has been accomplished in aircraft flight tests, using photoelectric spectrometry. Additional research in spectral signature analysis is required in this area. Again, the synoptic view from orbital altitude is advantageous, and target selection is important for examination of localized areas. These research areas are identified as acceptable candidates for space research.

Under the subobjective of determining the water budget of the earth, the application areas of water vapor in the atmosphere and precipitation will require the use of multiband passive microwave instrumentation, and secondarily, multiband infrared radiometry. Here wide geographic coverage is of primary importance, and high spatial resolution is secondary. The orbital characteristics of target selection and repeatable ground track may be of value for study of specific regions (i.e., arctic or tropical). Again, the other orbital characteristics and the characteristics of the space environment are not important, and the critical issues (research objectives) are candidates for space research, as exemplified by research to date in the discipline of meteorology.

The application area of snow and ice, pertaining to the water budget, covers three critical issues that are candidates for space research, as discussed previously under the application area of surface and subsurface water inventory. Determination of soil moisture has also been discussed under this same area.

Also under the subobjective of determining the water budget, the three application areas of snow and ice, soil moisture, and surface and subsurface water cover critical issues that are considered candidates for space research, by analogy with those under the area of surface and subsurface water inventory, previously discussed.

Investigation of the area of boundary layer phenomena, as it pertains to the energy budget of the earth, encompasses two critical issues, (1) measurement of the thermal flux from the earth into the atmosphere and (2) the horizontal distribution of water vapor flux. These are currently under study in the environmental science of meteorology, using instrumented spacecraft, and are obviously candidates for space research.

In summary, referring to Column 13 of Table 3-51, 69 of the critical issues that were identified in the organized overview analysis were judged to be suitable for space research, in either manned or automated space flight.

3.7.6.2 Screening of Critical Issues for Applicability to Research in Manned Space flight

The criteria for screening critical issues to determine their suitability for research in manned space flight were discussed in Subsection 3.7.1.3 and are used as headings in Columns 14 to 30 of Table 3-51.

It was found that the participation of man pertained generally to the requirements of all of the critical issues and was not unique to the requirements of individual issues. It will be discussed on that basis.

Referring to the table, the role of man as a scientist-observer, development engineer, or technician was considered helpful but not essential in nearly all cases. The first exception is in real-time communication of ground-sensor data (Critical Issue 6.5.1.1.1.3), where most of the criteria were found to be not applicable. The second exception was component qualification testing, where man's abilities were considered not applicable to the types of instruments that would be used in obtaining hydrologic data. The third exception is servicing the instrument consumables, where man's participation is mandatory.

The next group of criteria considered were those pertaining to flight safety. The environmental extremes of space were in all cases considered tolerable on the basis of previous experience in manned earth-orbiting missions. None of the experimental requirements are considered to exceed physiological limits, to cause psychological stress, or to affect crew safety. Therefore, these criteria were identified in all cases as being not applicable. Acceleration disturbances resulting from crew mobility were considered tolerable, as image motion compensation or onboard measurement of rates of change of spacecraft attitude can be provided to prevent degradation of high-resolution imagery. The effects of the release of effluents were considered tolerable, but the lenses of optical instruments should be protected from contamination by removable covers, which would be kept in place except when observations are being made. None of the experiment objectives will require repetitive duty cycles or extended observations in which the crew will have to perform high-precision manipulation of instruments; this criterion, therefore, was considered in all cases to be not applicable.

In summary, the participation of man was generally considered beneficial, and all but four of the critical issues examined were considered suitable for research in manned spaceflight, as indicated in Column 31 of Table 3-51.

3.7.6.3 Consideration of the Results of Previous and Ongoing Programs

The previous and current programs relating to the research objectives of the hydrology discipline that were considered are the Earth Resources Technology Satellites (ERTS) A and B, the exploratory and operational satellites of the National Meteorological Satellite System, manned missions including Gemini and Apollo and the aircraft tests conducted by the Manned Spacecraft Center and the Goddard Space Flight Center.

Under the application area of water management and flood control (Table 3-51), the feasibility of obtaining synoptic data for water system management will be explored by the Data Collection System of the ERTS satellite. Synoptic data in the form of low-resolution television imagery were obtained previously in the operational satellites of ESSA and have been used to some extent for flood warning and control. The objective of Critical Issue 6.5.1.1.1.1. is considered to be partially fulfilled and is a candidate for an earth-orbital experiment program. The second research objective, obtaining reliable data on storm flow concentration, is not being addressed to a satisfactory degree by previous and ongoing programs, and requires high-resolution photographic, infrared, and radar imagery that cannot be obtained with the instruments contemplated for these programs. Therefore no critical issues in this area were eliminated.

The third objective, real-time communication of ground-sensor-data, will be only partially fulfilled by the ERTS satellite Data Collection System. The Data Collection System can also obtain stream-flow data from ground sensors, providing initial support to the fourth objective, to obtain runoff data from snow packs. No critical issues will be completely fulfilled by previous and current programs and hence none were eliminated.

The second application area, inventory of surface and subsurface water, involves eight research objectives. The areal extent and location of lakes and reservoirs (as demonstrated in Gemini and Apollo flights) can be obtained by photography supplemented by infrared and microwave instrumentation. Snow and ice surveys can be performed with this same instrumentation, as well as locating of large icebergs. Underground water sources can be identified with infrared instruments (at the point of discharge), and the areal extent of soil moisture can be determined with passive microwave radiometry. Preliminary contributions by the weather satellites and the MSC aircraft program are noted in Table 3-51.

Topographic information on river basins and underdeveloped regions, as identified in the third application area, can be obtained by photointerpretation of high-resolution photography, as demonstrated in Gemini and Apollo flights, and may be obtained directly in areas of large terrain relief by stereo photography from orbit. Supplemental data can be obtained by infrared imagery (under eclipse conditions) and by side-looking radar through cloud cover. Since the ongoing programs will only partially fulfill the research objectives in this category they are considered candidates for future manned space flight.

The fifth application area, requiring that data be obtained on water circulation patterns in coastal areas, estuaries, and lakes, has been demonstrated on previous manned missions and is also considered a candidate for future manned missions.

The area of water pollution is of particular importance, and spacecraft can offer the advantage of surveying selected areas of known pollution. In some cases, saline intrusion in estuaries can be sensed by color photography, and thermal infrared radiometric imagery can be used to sense the differences in temperature between fresh water discharge and ocean water. Algal blooms are clearly visible in false-color infrared photography, and oil slicks can be identified by high-resolution spectrophotometry. Based upon limited spectral and spatial resolution of the ERTS sensors, these research objectives are retained as candidates for the earth-orbital experiment program.

The seventh application area, related to the measurement of the amount and areal distribution of water vapor in the atmosphere, is of primary concern in the environmental science of meteorology. Previous infrared experiments and future passive microwave experiments in Nimbus satellites will provide initial data in this area but cannot be expected to fulfill the hydrologic research requirements completely.

The tenth application area, snow and ice, relates to obtaining scientific knowledge of the world's snow and ice cover to determine the percentage of water in the solid state in the total water budget of the earth. Preliminary data have been obtained in near-polar-orbiting meteorological satellites, using low-resolution television imagery. Automated spacecraft for the near term probably will not be capable of producing data of (1) higher resolution and (2) penetration of cloud cover with microwave instruments. The research objectives in this area are therefore selected as candidates for manned spaceflight.

Measurement of the global distribution of soil moisture is important in hydrology. Two specific uses of this information are in prediction of flooding conditions and determining the distribution of permafrost in arctic regions (of importance in engineering construction). Soil moisture is also of interest in agricultural studies. Automated spacecraft could be restricted in their ability to carry large antennas that enable spatial resolution to be increased. This area is also selected as a candidate for manned spaceflight.

Measurement of the water content of lakes and rivers can be fulfilled in part by observations from space. The areal extent of surface water can be obtained directly by photography and by infrared and radar imagery. Topography can be defined by photographic interpretation, but ground measurements are desirable for determining water depth. This item is related to the second application area, inventory of surface and subsurface water, and is selected as a candidate for the earth-orbital experiment program.

In summary, all of the 64 critical issues previously identified as candidates for manned spaceflight (Column 31, Table 3-51) were retained and are considered candidates for a manned earth-orbital experiment program.

3.7.6.4 Grouping of Critical Issues by Experimental Approach

In the organized overview analysis (Section 2), the correlation of NASA goals and objectives and the correlation of scientific and technological objectives within the environmental science of hydrology resulted in identifying major subobjectives and specific application areas related to each subobjective. Within each application area, specific critical issues (research objectives) have been defined.

As discussed in the previous section, it is evident that some of the applicatior areas are related. The data requirements of a number of the critical issues are also related, primarily from the standpoints of commonality in observables (hydrologic features on the earth from which data are desired) and commonality in instrumentation. It was found possible, through commonality, to combine the requirements of the 64 critical issues into seven research clusters that serve as a basis for experimental research in space.

The clusters formed on the basis of these considerations are identified and listed below:

1. Determination of Pollution in Water Resources
2. Flood Warning and Damage Assessment
3. Synoptic Inventory of Major Lakes and Reservoirs
4. Synoptic Inventory of Snow and Ice
5. Survey of Soil Moisture in Selected Areas of the North American Continent
6. Location of Underground Water Sources in Selected Areas
7. Survey of Hydrologic Features of Major River Basins

A brief description of the corresponding research clusters is presented at the end of Subsection 3.7. More detailed information may be found in Appendix C.

3.7.7 Screening and Grouping of Critical Issues in Oceanography and Marine Resources

The oceans of the world cover approximately 71 percent of the earth's surface. The land surface is distributed in such a manner that the percentage of the oceans in broad latitude belts increases almost continuously from 30 percent water near 70 degrees north to greater than 99 percent near 60 degrees south. For the whole Northern Hemisphere, approximately 61 percent is covered by water compared with 81 percent in the Southern Hemisphere.

Traditionally, ocean data have been acquired from ships, although this is a slow, costly method. Using ships of opportunity in recent years has increased coverage at a minimum of cost, but the information needed for increasing knowledge for conservation and utilization of the oceans requires an order-of-magnitude increase in expense if this traditional approach is continued. Alternative approaches can make use of buoys, aircraft, and spacecraft. Techniques for using these platforms in acquiring research or operational data are now under development. Future research and operational data systems will probably use a mix of all of these platforms.

The screening of 62 of the 84 critical issues in Oceanography is displayed in the matrix of Table 3-52 and is discussed below.

3.7.7.1 Screening for Space-Research Applicability

Space platforms offer several advantages for acquiring oceanography information. The fundamental advantage for oceanography is the ability of a space platform to provide wide geographic coverage together with a repeatable ground track. There are a number of possible tradeoffs between the coverage and the repeatability. The desirable combination is different for each research or operational problem and must be considered with respect to the overall set of information objectives. An advantage of manned space platforms is the ability to test and modify measurement techniques and instruments prior to integration into an overall operational satellite system. Other advantages of manned space platforms are a flexible target selection capability and the specialized data-acquisition programs using multiple sensors.

To utilize space platforms to obtain useful measurements and information for research or operational applications requires that a remote sensor observation system and associated data-processing techniques be developed or improved. This necessitates that the information and measurements requirements be anticipated; i.e., the decisions, predictions, or research objectives (critical issues) to be satisfied must be determined. To determine which critical issues should be considered for such space platform observation systems, it was necessary to determine whether parameters of emitted, scattered, or reflected radiation could theoretically be used for determining the necessary information. If this appeared possible, the critical issue was not screened out, even though sensors or techniques were not currently available or under development.

This rationale was based on the assumption that the ensuing research would be part of an evolutionary program to develop an effective system. In particular, it would appear that the less unproved or untried the technique or instrument, the greater would be the need for research and development before it could be used on an unmanned operational satellite. As an example, consideration can be given to the measurement of the spectral radiance of the sea surface to estimate the chlorophyll amount, and hence the abundance of plankton in the ocean. Although this technique has been suggested as feasible by testing in aircraft, it may not be immediately successful when used on a spacecraft because of radiance from other sources in the atmosphere and ocean. Another example is the use of polarized microwave emission from the ocean for determining salinity. Theoretically this has been shown possible, but feasibility has not been demonstrated. Still another example is the proposed use of radar altimetry for determining mean sea height. This has potential from theoretical considerations but has not yet been tried.

In summary, referring to Column 13 of Table 3-52, 57 of the 62 critical issues screened were deemed suitable for space research and were considered in the subsequent screening.

3.7.7.2 Screening for Applicability of Manned Space Research

These examples suggest that there is a need for a manned space facility in which to conduct scientific, developmental, and operational research. Such a facility would conduct experiments with objectives that would utilize man in a broad spectrum of roles, such as scientist, development engineer, or technician. As a scientist, he might have the role as the principal investigator, coinvestigator, or scientist-observer.

Man in the role of scientist, engineer, or technician could perform activities in the following functional categories:

Table 3-52
SCREENING OF CRITICAL ISSUES IN OCEANOGRAPHY

*DEFINITION OF SYMBOLS
E = ESSENTIAL
H = HELPFUL
N = NO EFFECT
T = TOLERABLE
I = INTOLERABLE
U = EFFECTS UNKNOWN
NA = NOT APPLICABLE

			CRITICAL ISSUES	SPACE RESEARCH SELECTION CRITERIA: ORBITAL CHARACTERISTICS: ORBITAL ALTITUDES	WIDE AREAL (GEOGRAPHIC) COVERAGE	TARGET SELECTION	REPEATABLE GROUND TRACK	ORBITAL VELOCITY/ALTITUDE (V/H) RATIO	RELATIVE VELOCITY	SPACE ENVIRONMENT CHARACTERISTICS: GRAVITATIONAL EFFECTS	ATMOSPHERE (VACUUM)	METEOROIDS	ATMOSPHERIC ATTENUATION	COSMIC RADIATION	RADIATION BELTS	CRITICAL ISSUE IS SUITABLE FOR SPACE RESEARCH (√)	MANNED SPACE RESEARCH SELECTION CRITERIA: PARTICIPATION OF MAN: SCIENTIST/OBSERVER: REAL TIME DATA ANALYSIS AND EVALUATION	MULTIPLE SENSOR USE	SENSOR MODE AND PARAMETER SELECTION	COOPERATION WITH PRINCIPAL INVESTIGATOR ON THE GROUND	DEVELOPMENT ENGINEER: TARGET SELECTION	SENSOR OPERATION AND PARAMETER VARIATION	EVALUATION OF SENSOR DESIGN AND PERFORMANCE	COMPONENT QUALIFICATION TESTING	TECHNICIAN: EQUIPMENT SETUP, CHECKOUT, MAINTENANCE, AND CALIBRATION	SERVICING OF SENSOR AND EQUIPMENT CONSUMABLES	FLIGHT SAFETY: EXTERNAL ENVIRONMENTAL EXTREMES (RADIATION, TEMPERATURE, VACUUM, ETC.)	EXCEEDS PHYSIOLOGICAL LIMITS (WEIGHTLESSNESS, FATIGUE, ETC.)	EXCESSIVE PSYCHOLOGICAL STRESS (SENSORY DEPRIVATION, ETC.)	AFFECTS CREW SAFETY (HIGH VOLTAGE, NOISE LEVEL, INFLAMMABLES, ETC.)	MISSION PERFORMANCE DEGRADATION: ACCELERATION (POINTING, STABILITY, ATTITUDE CONTROL)	EFFLUENT RELEASE (CONTAMINATION)	REPETITIVE DUTY CYCLES (CONTINUOUS, HIGH FREQUENCY OBSERVATIONS)	CRITICAL ISSUE IS SUITABLE FOR MANNED SPACE RESEARCH (√)	RELATIONSHIP TO OTHER PROGRAMS: PROGRAM ON WHICH PRELIMINARY INFORMATION HAS BEEN DEVELOPED	PROGRAM COMPLETELY SATISFYING EXPERIMENT REQUIREMENTS	RESEARCH REQUIREMENTS NOT SATISFIED BY OTHER PROGRAMS (√)	CRITICAL ISSUE IS CANDIDATE FOR FUTURE MANNED SPACE RESEARCH (√√)
KNOWLEDGE / STATE	GEOPHYSICAL	6.6.1.1.1.1	How does the sea surface height vary because of variations in the Earth's gravitational potential?	E	E	N	E	NA	N	N	N	T	T	T	T	√	N	N	H	E	N	H	H	E	H	H	H	N	N	N	N	N	N	√			√	√√
		6.6.1.1.1.5	What are the relationships between bottom topography and tsunamis?	H	H	N	H	NA	N	N	N	T	T	T	T	√	H	E	H	H	N	H	H	H	H	E	N	N	N	N	N	N	N	√			√	√√
	PHYSICAL	6.6.1.1.2.1	How are tidal flushing patterns affected by coastline construction?	H	H	E	E	NA	T	N	N	T	T	T	T	√	H	N	H	H	E	H	H	H	H	E	N	N	N	N	N	N	N	√			√	√√
		6.6.1.1.2.2	How are the physical properties affected by ocean pollution?	H	E	E	E	NA	T	N	N	T	T	T	T	√	E	E	H	E	E	E	E	E	H	E	N	N	N	N	N	N	N	√			√	√√
		6.6.1.1.2.3	What are the relationships between energy partition at the ocean surface and atmospheric and ocean characteristics and phenomena?	H	E	E	E	NA	T	N	N	T	T	T	T	√	H	E	H	E	H	E	E	E	H	H	H	N	N	N	N	N	N	√			√	√√
		6.6.1.1.2.4	What are the relationships between distribution of ocean variables on the small scale and ocean turbulence and other motion?	H	E	E	E	NA	T	N	N	T	T	T	T	√	H	H	H	E	E	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.1.2.5	How can knowledge of the bottom topography be improved?	H	H	E	H	NA	T	N	N	T	T	T	T	√	E	H	H	H	E	H	H	H	H	E	N	N	N	N	N	N	N	√			√	√√
	CHEMICAL	6.6.1.1.3.1	How is the salinity field of the ocean surface affected by precipitation, evaporation and runoff from land?	H	H	E	E	NA	T	N	N	T	T	T	T	√	H	H	H	H	E	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.1.3.2	How does ocean pollution affect electromagnetic emission from the sea surface?	H	H	E	E	NA	T	N	N	T	T	T	T	√	H	E	H	H	E	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.1.3.3	How does ocean pollution affect the chemical reactions and salinity in the oceans?	H	H	E	E	NA	T	N	N	T	T	T	T	√	H	H	H	H	E	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.1.3.4	How does tidal flushing patterns affect salinity and pollution characteristics?	H	H	E	E	NA	T	N	N	T	T	T	T	√	H	N	H	H	E	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
	GEOLOGICAL	6.6.1.1.4.1	How do the volcanological characteristics of the ocean relate to the occurrence of tsunamis?	H	H	E	E	NA	T	N	N	T	T	T	T	√	E	E	H	H	E	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.1.4.2	How does aeolian transport affect the composition of sea water and sediments?	H	E	H	E	NA	T	N	N	T	T	T	T	√	N	N	H	N	H	H	H	H	N	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.1.4.3	What are the erosion and sedimentation characteristics of the coastlines?	H	H	E	E	NA	T	N	N	T	T	T	T	√	E	N	H	N	E	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.1.4.4	What is the relationship between sediment character and physical characteristics?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
	BIOLOGICAL	6.6.1.1.5.1	What is the population dynamics of the ocean?	H	H	H	E	NA	T	N	N	T	T	T	T	√	E	H	H	H	H	H	H	E	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.1.5.2	How is the productivity of the ocean related to ocean pollution?	H	E	H	E	NA	T	N	N	T	T	T	T	√	E	H	H	H	H	H	H	E	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.1.5.3	How is the population distribution of the biota affected by cloud cover and precipitation?	H	E	E	E	NA	T	N	N	T	T	T	T	√	E	H	H	E	E	H	H	H	H	E	N	N	N	N	N	N	N	√			√	√√
		6.6.1.1.5.4	How can knowledge of the surface slicks be improved?	H	E	E	E	NA	T	N	N	T	T	T	T	√	H	N	H	H	E	H	H	E	H	H	N	N	N	N	N	N	N	√	TIROS, NIMBUS		√	√√
KNOWLEDGE / TRANSFORMATIONS	ENERGY	6.6.1.2.1.2.1	How is the partition of solar energy at the sea surface affected by the roughness, foaminess, oiliness, etc. of the surface?	H	H	H	E	NA	T	N	N	T	T	T	T	√	H	E	H	E	H	H	H	E	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.1.2.2	How is the emission of microwave and infrared radiation of the sea surface affected by the roughness, foaminess, oiliness, etc., of the surface?	H	H	E	E	NA	T	N	N	T	T	T	T	√	H	E	H	H	E	H	H	H	H	E	N	N	N	N	N	N	N	√			√	√√
	BIOTA	6.6.1.2.1.4.1	How is the nutrient distribution affected by turbulence in the ocean?	H	H	E	E	NA	T	N	N	T	T	T	T	√	H	E	H	H	E	E	H	E	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.1.4.2	How is the productivity modulated by short-term variations in the solar radiation that penetrates the ocean boundary?	H	E	H	E	NA	T	N	N	T	T	T	T	√	H	H	H	H	H	H	H	E	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.1.4.3	How is the population dynamics affected by ocean pollution?	H	E	H	E	NA	T	N	N	T	T	T	T	√	E	H	H	E	H	H	H	E	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.1.4.4	How is the biota distribution affected by temperature and salinity changes?	H	E	E	E	NA	T	N	N	T	T	T	T	√	H	E	H	E	E	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
	SEDIMENTATION	6.6.1.2.1.5.1	How does turbulence affect the transport of particulate matter?	H	H	E	E	NA	T	N	N	T	T	T	T	√	N	H	H	H	E	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.1.5.2	How do turbidity currents affect the bottom topography of the ocean?	H	H	E	E	NA	T	N	N	T	T	T	T	√	N	H	H	H	E	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.1.5.3	How do the biological processes affect the depositional characteristics?	H	H	E	E	NA	T	N	N	T	T	T	T	√	H	H	H	H	E	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
KNOWLEDGE / CHANGE PREDICTION	DATA	6.6.1.2.2.1.1	How can operational data be separated efficiently from research data?	H	H	N	E	NA	N	N	N	T	T	T	T	√	H	H	H	H	N	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.2.1.2	How can operational data be transmitted more quickly and accurately?	H	H	H	E	NA	N	N	N	T	T	T	T	√	H	H	H	H	N	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.2.1.3	How can the representativeness of sea surface data be improved?	H	H	N	E	NA	N	N	N	T	T	T	T	√	H	H	H	H	N	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.2.1.4	How can the time between data acquisition and processed results to the user be improved?	H	H	N	E	NA	N	N	N	T	T	T	T	√	H	H	H	H	N	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.2.1.5	What ground truth data is needed to improve data accuracy?	H	H	N	E	NA	N	N	N	T	T	T	T	√	H	H	H	H	N	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.2.2.1	How can forecasts of the density be improved?	H	E	H	E	NA	T	N	N	T	T	T	T	√	H	E	H	H	H	H	H	H	H	E	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.2.2.2	How can forecasts of movements of silt and sand be improved?	H	H	H	E	NA	T	N	N	T	T	T	T	√	H	H	H	H	H	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.2.2.3	How can forecasts of salinity be improved?	H	E	H	E	NA	T	N	N	T	T	T	T	√	H	H	H	H	H	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.2.2.4	How can forecasts of nutrients be improved?	H	E	H	E	NA	T	N	N	T	T	T	T	√	E	E	H	H	H	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.2.2.5	How can forecasts of fish population be improved?	H	E	H	E	NA	T	N	N	T	T	T	T	√	E	E	H	H	H	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.2.2.6	How can forecasts of tides be improved?	H	E	H	E	NA	T	N	N	T	T	T	T	√	H	H	H	H	H	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.2.2.7	How can forecasts of storm surges be improved?	H	E	H	E	NA	T	N	N	T	T	T	T	√	H	H	H	H	H	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.2.2.8	How can forecasts of tidal waves be improved?	H	E	H	E	NA	T	N	N	T	T	T	T	√	H	H	H	H	H	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.2.2.10	How can forecasts of icebergs and ice movement be improved?	H	E	E	E	NA	T	N	N	T	T	T	T	√	H	H	N	H	E	N	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.2.2.11	How can forecasts of rough seas be improved?	H	E	H	E	NA	T	N	N	T	T	T	T	√	E	H	H	H	E	H	H	H	H	H	N	N	N	N	N	N	N	√	ATS-3		√	√√
		6.6.1.2.2.2.12	How can forecasts of mean sea surface height be improved?	E	E	N	E	NA	N	N	N	T	T	T	T	√	H	N	N	H	E	N	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.2.2.13	How can forecasts of ocean currents be improved?	H	E	H	E	NA	T	N	N	T	T	T	T	√	E	E	H	E	H	E	H	H	H	E	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.2.2.14	How can forecasts of upwelling be improved?	H	E	H	E	NA	T	N	N	T	T	T	T	√	E	E	H	E	H	E	H	H	H	E	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.2.2.15	How can forecasts of dilution be improved?	H	E	H	E	NA	T	N	N	T	T	T	T	√	H	E	H	E	H	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.2.2.16	How can forecasts of sea surface temperature fields be improved?	H	E	H	E	NA	T	N	N	T	T	T	T	√	H	H	H	H	H	H	H	H	H	H	N	N	N	N	N	N	N	√	TIROS, NIMBUS		√	√√
		6.6.1.2.2.2.17	How can forecasts of sea temperature with depth be improved?	H	E	H	E	NA	T	N	N	T	T	T	T	√	H	H	H	H	H	H	H	H	H	E	N	N	N	N	N	N	N	√	TIROS, NIMBUS		√	√√
		6.6.1.2.2.2.18	How can forecasts of mixed layer depths be improved?	H	E	H	E	NA	T	N	N	T	T	T	T	√	H	H	H	H	H	H	H	H	H	E	N	N	N	N	N	N	N	√	TIROS, NIMBUS		√	√√
		6.6.1.2.2.2.20	How can forecasts of heavy swell on coasts be improved?	H	E	N	E	NA	T	N	N	T	T	T	T	√	E	H	H	H	E	H	H	H	H	H	N	N	N	N	N	N	N	√	ATS-1		√	√√
		6.6.1.2.2.2.21	How can forecasts of convergence zones be improved?	H	E	H	E	NA	T	N	N	T	T	T	T	√	E	E	H	E	H	H	H	H	H	E	H	N	N	N	N	N	N	√			√	√√
	TECHNOLOGY	6.6.1.2.2.3.1	What oceanographic instruments need further development to improve data needed for prediction?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.6.1.2.2.3.2	What improvements in computational facilities are needed?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.6.1.2.2.3.3	What improvements in communications are needed?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
		6.6.1.2.2.3.4	What improvements in display facilities are needed?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																							
MODIFICATION	AIR/SEA BOUNDARY	6.6.1.2.3.1.1	How much affect does a sea surface film of oil have on evaporation sensible heat flux and gas exchange?	H	E	E	H	NA	T	N	N	T	T	T	T	√	H	E	H	H	E	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.3.1.2	How much affect does an oil film have on the character of wind stress and momentum flux on the ocean surface?	H	E	H	E	NA	T	N	N	T	T	T	T	√	H	E	H	H	H	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
	SOLID BOUNDARY	6.6.1.2.3.2.1	How do jetties and land fill affect longshore transport?	H	H	E	E	NA	T	N	N	T	T	T	T	√	N	H	H	H	E	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
	INTERNAL BOUNDARIES	6.6.1.2.3.3.1	How are population dynamics affected by ocean pollution?	H	E	H	E	NA	T	N	N	T	T	T	T	√	E	H	H	H	H	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.3.3.2	How does changing the sea color affect ocean heating and photosynthesis?	H	E	H	E	NA	T	N	N	T	T	T	T	√	H	H	H	H	H	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√
		6.6.1.2.3.3.3	How can pollution of the ocean be effectively controlled?	H	E	E	E	NA	T	N	N	T	T	T	T	√	E	H	H	E	E	H	H	H	H	H	N	N	N	N	N	N	N	√			√	√√

1. Laboratory research in physics, chemistry, or biology, using pertinent space environment characteristics.
2. Research and development in imprcving observation systems, utilizing remote sensing techniques.
3. Research and development on measurement techniques, related sensors, and associated electronics.
4. Research and development in data processing, compression, and telemetry to improve relevant information flow.
5. Research and development for physical description and related mathematical modeling for prediction and utilization purposes.
6. Specialized data acquisition to satisfy research or operational requirements of a transient nature.
7. Routine monitoring or inventorying of the earth where complexity of the observational system makes the use of man desirable or necessary.
8. Training for the better utilization of data from current or future operational systems.

Examples in Oceanography for each of these categories are described in the following paragraphs.

Laboratory experiments desirable in Oceanography that utilize space environment characteristics appear limited at present. One such experiment could utilize the zero-gravity characteristic to simulate the evaporation of spray and foam to determine salt particle size and charge distribution. For this or similar experiments, man would have the role of scientist.

In the category of improving observation systems is the remote sensing of sea-surface temperature with infrared radiometers. At present, this technique is limited by a lack of knowledge of the microphysics of the thin surface layer and by cloud cover. Heating, evaporation, spray, foam, and oil films affect the emissive and reflectance properties of the sea surface. These factors make it difficult to interpret the radiometric values in terms of temperature. Research is needed that utilizes surface and aircraft platforms, together with space platforms to resolve the degree of influence of these effects. Although the infrared technique is limited by clouds, microwave radiation theoretically penetrates clouds, and its measurement therefore has been proposed for the determination of sea-surface temperature. The variability of the thickness, type, and spatial distribution of clouds, however, will have an effect on the radiation, as will the aforementioned sea-surface characteristics. Research is needed, therefore, to determine these effects. It may be that a combination of the two techniques can be used to improve and extend the remote sensing of the sea-surface temperature. Another example in this category is the technique for using two frequencies, either in the infrared or microwave band, to estimate the heat flow at the sea surface.

The next category contains the proposed method of determining chlorophyll from the measurement of the spectral radiance of the sea surface. This method is affected by the light scattered from clouds in the atmosphere, the sea's surface, materials or organisms suspended in the water, the sea's bottom, and discoloration from pollution. Further research is required to determine what associated surface or spacecraft measurements are needed to account for these effects or to allow their simultaneous measurement. Another example is the proposed technique of using radar altimeters for measuring the variation in the mean sea-surface height. This requires, among other things, experimenting with the radar signal to determine the best combination of pulse characteristics and averaging processes.

The category of data processing, compression, and telemetry contains the development of computer models that use inputs from multiple sensors to determine measurement values of many physical parameters and variables. Another example in this category is the development of techniques and computer algorithms to scan the sensor inputs to recognize specific phenomena of interest. Only data on these phenomena would be stored or transmitted.

The category of physical description and related mathematical modeling would include research using sensor inputs and ground data to improve knowledge on specific phenomena or processes. An example here would be that of relating sea-surface temperature changes to heat flow through the sea surface and changes in the surface wind stress. Another example is the improvement of techniques for forecasting the swell at locations distant from the sea-surface roughness observed from multiple sensor measurements. Still another example is the development of techniques for estimating the best fishing areas via remote sensing.

In the category of research or operational requirements of a transient nature are such things as plankton blooms, oil spills, tsunamis, tidal waves, storm surges from hurricanes, coastal damage assessments, and leads in ice packs.

For routine monitoring or inventorying utilizing complex equipment, man may be desirable or necessary to select, set up, adjust, activate, or monitor equipment; point instruments; select filters; expose film; request ground support; and process and evaluate data.

The last category, training, would involve scientists, engineers, or administrators who, because of the nature of their work functions, could profit from a tour of duty in a space research facility. Their activities on such a training tour would be tailored to enable them to better evaluate, interpret, or utilize data from manned or unmanned space platforms.

In summary, all critical issues previously identified as candidates for space research were retained as candidates for manned space research (Column 31, Table 3-52).

3.7.7.3 Contributions of Ongoing Programs

TIROS and NIMBUS satellites provide data from infrared radiometers that have been used for sea surface temperature and sea ice investigations. Although these data have been quite useful, they have the limitations discussed above, and the spatial resolution is not good enough. ERTS A and B satellites will have multichannel imaging spectrometers and multichannel cameras that will provide data with surface resolutions of about 300 ft. However, the spectral response of these sensors does not include the region of greatest interest to oceanography (the 350 to 450 millimicron band) where discrimination of chlorophyl and blue-green algae is the strongest.

In summary, a review of the ongoing programs reveals that the oceanic parameters of critical interest will not be available from TIROS, NIMBUS, or ERTS. While some meteorological phenomena of interest to oceanographers will be produced by these programs, the problems of solar energy partition, sea surface conditions, air-sea interaction, and marine biological studies still remain to be addressed. Hence, no critical issues were eliminated by the screening of ongoing programs.

3.7.7.4 Grouping of Critical Issues Into Research Clusters

The critical issues that have been formulated from the organized overview methodology and screened by the relationship criteria for space, manned, and other programs have been grouped into research clusters by considering the commonality of information requirements. This procedure has resulted in seven research clusters: 6-0-1, Ocean Pollution Identification, Measurement, and Effects; 6-0-2, Solar Energy Partition and Heating in the Sea Surface Layer; 6-0-3, Ocean Population Dynamic and Fishery Resources; 6-0-4, Ocean Currents and Tide Forecasting; 6-0-5, Ocean Physical Properties; 6-0-6, Ocean Solid Boundary Processes; and 6-0-7, Ocean Surface Activity Forecasting.

3.7.7.5 Brief Description of the Research Clusters

In summary, in the subdiscipline of Oceanography, seven research clusters were formed from the 64 critical issues judged suitable for a manned earth-orbital research program. A brief description of these research clusters is presented at the end of Subsection 3.7. More detailed descriptions may be found in Appendix C.

3.7.8 Screening and Grouping of Critical Issues in Meteorology

The long-range goal for meteorlogy is that man acquire sufficient understanding of atmospheric conditions and the processes of formation and change in the atmosphere to permit prediction of the future state of the atmosphere so that the environment may be modified and controlled. Modification and control of the environment are the end objectives in meteorology. The aim is to produce deliberate, beneficial changes in the environment and to bring under control or prevent changes that are damaging to society.

Pursuit of the long-range goal in meteorology requires that both necessary and sufficient conditions be satisfied in a sequential manner. The sequence of steps that must be taken can be stated as observation, description, understanding, prediction, modification, and control. For example, progress toward better weather prediction is limited by deficiencies in our basic understanding of the whole atmosphere.

The critical issues derived in the organized overview analysis were screened in accordance with the criteria set forth in Subsection 3.7.1.1 for selection as candidates for an earth-orbital experiment program. Fifty-six of these critical issues are shown in Table 3-53, which summarizes the screening of the critical issues in Meteorology.

3.7.8.1 Screening for Space Research Applicability

The 56 critical issues screened in Meteorology were first assessed as candidates for space research on the basis of the earth-orbital and spacecraft environment characteristics described in Subsection 3.7.1.2, as shown in Table 3-53.

An understanding of the role of space in meteorology requires an understanding of the basic characteristics of the observational problem and the technological system elements responsive to these characteristics.

The initial step in the pursuit of the long-range goal for meteorology is observation. Traditionally, meteorologists have worked under the disadvantage of having only a fragmentary knowledge of the state of the atmosphere at any given time. The attempt to increase this knowledge has led to the development and expansion (both geographically and in altitude) of observational networks to provide a wide spectrum of in situ land, sea, and airborne measurements. The systems providing these measurements, however, are not and (for practical reasons) cannot be uniformly distributed over the earth.

Table 3-53

SCREENING OF CRITICAL ISSUES IN METEOROLOGY

PROGRAM KEYS

A = NASA-MSC AIRCRAFT PROGRAM
B = MANNED MISSIONS (MERCURY, GEMINI, APOLLO)

DEFINITION OF SYMBOLS

E = ESSENTIAL
H = HELPFUL
N = NO EFFECT
T = TOLERABLE
I = INTOLERABLE
U = EFFECTS UNKNOWN
NA = NOT APPLICABLE

Space Research Selection Criteria: Orbital Characteristics (Orbital Altitudes; Wide Areal (Geographic) Coverage; Target Selection; Repeatable Ground Track; Orbital Velocity/Altitude (V/H) Ratio; Relative Velocity); Space Environment Characteristics (Gravitational Effects; Atmospheric (Vacuum); Meteoroids; Atmospheric Attenuation; Cosmic Radiation; Radiation Belts).

Manned Space Research Selection Criteria: Participation of Man — Scientist/Observer (Real Time Data Analysis and Evaluation; Multiple Sensor Use; Sensor Mode and Parameter Selection; Cooperation with Principal Investigator); Development Engineer (Careful Selection; Sensor Operation and Parameter Variation; Evaluation of Sensor Design and Performance; Component Qualification Testing); Technician (Equipment Setup, Checkout, Maintenance, and Calibration; Servicing of Sensor and Equipment, Consumables); Flight Safety (External Environmental Extremes (Radiation, Temperature, Vacuum, etc.); Excessive Physiological Limits; Toxicity, Pyrotechnics, Explosives, etc.; Affects Crew Safety (High Voltage, Noise Levels, Inflammables, etc.)); Mission Performance Degradation (Affects Orientation Control, Crew Mobility, etc.; Environmental Contamination; High Duty Cycle (Continuous Observation)).

Category	Number	Critical Issue	Orbital Altitudes	Wide Areal Coverage	Target Selection	Repeatable Ground Track	Orbital V/H Ratio	Relative Velocity	Gravitational Effects	Atmospheric (Vacuum)	Meteoroids	Atmospheric Attenuation	Cosmic Radiation	Radiation Belts	Critical Issue Is Suitable for Space Research (√)	Real Time Data Analysis and Evaluation	Multiple Sensor Use	Sensor Mode and Parameter Selection	Cooperation with Principal Investigator	Careful Selection	Sensor Operation and Parameter Variation	Evaluation of Sensor Design and Performance	Component Qualification Testing	Equipment Setup, Checkout, Maintenance, Calibration	Servicing of Sensor and Equipment, Consumables	External Environmental Extremes	Excessive Physiological Limits	Toxicity, Pyrotechnics, Explosives	Affects Crew Safety	Affects Orientation Control, Crew Mobility	Environmental Contamination	High Duty Cycle (Continuous Observation)	Critical Issue Is Suitable for Manned Space Research (√)	Program on Which Preliminary Information Has Been Developed	Program Completely Satisfying Experiment Requirements	Research Requirements Not Satisfied by Other Programs (√)	Critical Issue Is Candidate for Future Manned Space Research (√√)
STATE — ACCRETION	6.7.2.1.2.1	How can the analysis of micrometeoroids, planetesimals, and other extraterrestrial particles aid in the understanding of the formation of the atmosphere?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																								
ORIGINAL COMPONENT	6.7.2.1.3.1	How can the mapping of geologic rhythms advance our understanding of the origin of the atmosphere?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																								
	6.7.2.1.3.2	How can the study of volcanic activity and magma aid in the understanding of the origin of the atmosphere?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																								
	6.7.2.1.3.3	How can the survey of limestone and dolomite deposits help the understanding of the origin of the atmosphere?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																								
CHEMICAL	6.7.2.2.1.1	What chemical constituents are present in the atmosphere?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																								
	6.7.2.2.1.2	Where are the chemical constituents located and how do they vary?	E	E	H	E	T	E	N	N	T	E	T	T	√	H	H	H	H	H	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A	NONE	√	√√
	6.7.2.2.1.3	What terrestrial and extraterrestrial factors affect the distribution of chemical constituents?	E	E	H	E	T	E	N	N	T	E	T	T	√	H	H	H	H	H	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A	NONE	√	√√
PHYSICAL	6.7.2.2.2.1	What knowledge of the present state of the physical characteristics is required?	E	E	H	E	T	E	N	N	T	E	T	T	√	H	H	H	H	H	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A	NONE	√	√√
	6.7.2.2.2.2	What knowledge of the present state of the physical characteristics is required?	E	E	E	E	T	E	E	N	T	E	T	T	√	H	H	H	H	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A,B	NONE	√	√√
CIRCULATION	6.7.2.2.3.1	What factors are involved in the current atmospheric momentum and mass fields?	E	E	E	E	T	E	E	N	T	E	T	T	√	H	H	H	H	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A,B	NONE	√	√√
	6.7.2.2.3.2	What factors are involved in the current atmospheric radiation and temperature fields?	E	E	H	E	T	E	N	N	T	H	T	T	√	H	H	H	H	H	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A,B	NONE	√	√√
	6.7.2.2.3.3	What factors are involved in the current atmospheric composition and structure?	E	E	H	E	T	E	N	N	T	H	T	T	√	H	H	H	H	H	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A,B	NONE	√	√√
CHANGE OF STATE — MOMENTUM AND MASS	6.7.2.3.1.1.1	What are the effects of the horizontal and vertical advection of velocity on the local time change of horizontal velocity?	E	E	H	E	T	E	N	N	T	H	T	T	√	H	H	H	H	H	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A,B	NONE	√	√√
	6.7.2.3.1.1.2	What is the effect of the acceleration by the pressure gradient force on the local time change of horizontal velocity?	E	E	H	E	T	E	N	N	T	E	T	T	√	H	H	H	H	H	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A	NONE	√	√√
	6.7.2.3.1.1.4	What is the effect of the acceleration by the frictional force due to internal eddy stresses on the local time change of horizontal velocity?	E	E	H	E	T	E	N	N	T	E	T	T	√	H	H	H	H	H	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A	NONE	√	√√
	6.7.2.3.1.1.5	What is the effect of the acceleration by the frictional force due to boundary layer stresses on the local time change of horizontal velocity?	E	E	H	E	T	E	N	N	T	E	T	T	√	H	H	H	H	H	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A	NONE	√	√√
HEAT	6.7.2.3.1.2.1	What are the effects of the horizontal and vertical advection of temperature on the local time change of temperature?	E	E	H	E	T	E	N	N	T	E	T	T	√	H	H	H	H	H	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A	NONE	√	√√
	6.7.2.3.1.2.2	What is the effect of the transfer of heat by adiabatic processes due to the individual pressure change on the local time change of temperature?	E	E	H	E	T	N	N	N	T	E	T	T	√	H	H	H	E	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A,B	NONE	√	√√
	6.7.2.3.1.2.3	What is the effect of diabatic heating by radiative transfer on the local change of temperature?	E	E	H	E	T	N	N	N	T	E	T	T	√	H	H	H	H	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A,B	NONE	√	√√
	6.7.2.3.1.2.4	What is the effect of diabatic heating by latent heat release on the local time change of temperature?	E	E	H	E	T	N	N	N	T	E	T	T	√	H	H	H	H	E	E	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A,B	NONE	√	√√
	6.7.2.3.1.2.5	What is the effect of diabatic heating by internal eddy heat diffusion on the local time change of temperature?	E	E	H	E	T	N	N	N	T	E	T	T	√	H	H	H	H	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A,B	NONE	√	√√
	6.7.2.3.1.2.6	What is the effect of diabatic heating by boundary layer heat transfer on the local time change of temperature?	E	E	H	E	T	N	N	N	T	E	T	T	√	H	H	H	H	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A,B	NONE	√	√√
COMPOSITION AND STRUCTURE	6.7.2.3.1.3.1	How is the water vapor field changed by advection and eddy diffusion?	E	E	H	E	T	N	N	N	T	E	T	T	√	H	H	H	H	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A,B	NONE	√	√√
	6.7.2.3.1.3.2	How is the water vapor field changed by evaporation and condensation?	E	E	H	E	T	N	E	N	T	E	T	T	√	H	H	H	H	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A,B	NONE	√	√√
	6.7.2.3.1.3.3	How are the water droplet and ice crystal cloud fields changed by advection and eddy diffusion?	E	E	H	E	T	N	E	N	T	E	T	T	√	H	H	H	H	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A,B	NONE	√	√√
	6.7.2.3.1.3.4	How are the water droplet and ice crystal fields changed by direct condensation, sublimation, and freezing?	E	E	H	E	T	N	E	N	T	E	T	T	√	H	H	H	H	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A,B	NONE	√	√√
	6.7.2.3.1.3.5	How are the water droplet and ice crystal fields changed by collision, coalescence, and colloidal instability?	E	E	H	E	T	N	E	N	T	E	T	T	√	H	H	H	H	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A,B	NONE	√	√√
	6.7.2.3.1.3.6	How is the ozone field changed by horizontal and vertical advection and eddy diffusion?	E	E	H	E	T	N	E	N	T	E	T	T	√	H	H	H	H	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A,B	NONE	√	√√
	6.7.2.3.1.3.7	How is the ozone field changed by photochemical dissociation or reduction and combination?	E	E	H	E	T	N	E	N	T	E	T	T	√	H	H	H	H	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A,B	NONE	√	√√
	6.7.2.3.1.3.8	How is the hygroscopic aerosol field changed by advection, eddy diffusion, and wind lifting of soil particles?	E	E	H	E	T	N	E	N	T	E	T	T	√	H	H	H	H	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A,B	NONE	√	√√
	6.7.2.3.1.3.9	How is the hygroscopic aerosol field changed by evaporation of sea spray and sea bubbles?	E	E	H	E	T	N	E	N	T	E	T	T	√	H	H	H	H	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	NONE	NONE	√	√√
	6.7.2.3.1.3.10	How is the hygroscopic aerosol field changed by condensation scavenging and precipitation washout?	E	E	H	E	T	N	E	N	T	E	T	T	√	H	H	H	H	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	NONE	NONE	√	√√
	6.7.2.3.1.3.11	How is the nonhygroscopic aerosol field changed by advection, eddy diffusion, and wind lifting of soil particles?	E	E	H	E	T	N	E	N	T	E	T	T	√	H	H	H	H	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	NONE	NONE*	√	√√
	6.7.2.3.1.3.12	How is the nonhygroscopic aerosol field changed by precipitation washout?	E	E	E	E	T	E	N	N	T	E	T	T	√	H	H	H	H	H	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	NONE	NONE	√	√√
CHANGE — PREDICTION — SHORT-RANGE FORECASTS	6.7.2.3.2.1.1	What knowledge is required of the changes in the momentum, temperature and mass fields including local real heating and radiation?	E	E	E	E	T	E	N	N	T	E	T	T	√	H	H	H	H	H	H	H	H	–	H	T	NA	NA	NA	T	T		√	A,B	NONE	√	√√
	6.7.2.3.2.1.2	How can numerical, statistical, empirical or other real time techniques be used?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																								
	6.7.2.3.2.1.3	What fast reaction data handling, warning and display facilities are required?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																								
	6.7.2.3.2.1.4	How can observations of the initial state of the time-dependent atmospheric variables be obtained and used?	E	E	H	E	T	E	N	N	T	E	T	T	√	H	H	H	H	H	H	H	H	H	H	T	NA	NA	NA	T	T		√	A	NONE	√	√√
EXTENDED RANGE FORECASTS	6.7.2.3.2.2.1	What knowledge is required of the changes in the momentum temperature and mass fields?	E	E	E	E	T	E	N	N	T	E	T	T	√	H	H	H	H	H	H	H	H	H	H	T	NA	NA	NA	T	T		√	A,B	NONE	√	√√
	6.7.2.3.2.2.2	How can high precision numerical, statistical, empirical or other techniques be used?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																								
	6.7.2.3.2.2.3	What large scale data handling and display facilities are required?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																								
	6.7.2.3.2.2.4	How can global observations of initial state of all the time-dependent atmospheric variables be obtained and used?	E	E	H	E	T	E	N	N	T	E	T	T	√	H	H	H	H	H	H	H	H	H	H	T	NA	NA	NA	T	T		√	A	NONE	√	√√
LONG-RANGE FORECASTS	6.7.2.3.2.3.1	What knowledge is required of the changes in the momentum, temperature and mass fields?	E	E	E	E	T	E	N	N	T	E	T	T	√	H	H	H	H	H	H	H	H	H	H	T	NA	NA	NA	T	T		√	A,B	NONE	√	√√
	6.7.2.3.2.3.2	How can the changes in the state of the ocean be used?	E	E	E	E	T	E	N	N	T	E	T	T	√	H	H	H	H	H	H	H	H	H	H	T	NA	NA	NA	T	T		√	A,B	NONE	√	√√
	6.7.2.3.2.3.3	How can advanced numerical, statistical, empirical or other techniques be used?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																								
	6.7.2.3.2.3.4	What global scale data handling and display facilities are required?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA																								
	6.7.2.3.2.3.5	How can global observations of the initial state of the time-dependent atmospheric variables be obtained and used?	E	E	H	E	T	E	N	N	T	E	T	T	√	H	H	H	H	H	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A	NONE	√	√√
	6.7.2.3.2.3.6	How can global observations of the initial state of the time-dependent land and oceanic variables be obtained and used?	E	E	H	E	T	E	N	N	T	E	T	T	√	H	H	H	H	H	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A	NONE	√	√√
MODIFICATION — BOUNDARY PROCESSES	6.7.2.3.3.1.1	What are the effects of changing the physical characteristics of the surface?	E	E	E	E	T	N	N	N	T	E	T	T	√	H	H	H	E	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A,B	NONE	√	√√
	6.7.2.3.3.1.2	What are the effects of changing the surface albedo and emissivity?	E	E	E	E	T	N	N	N	T	E	T	T	√	E	H	H	E	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A,B	NONE	√	√√
	6.7.2.3.3.1.3	What are the effects of changing the surface evaporation?	E	E	E	E	T	N	N	N	T	E	T	T	√	E	H	H	E	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A,B	NONE	√	√√
	6.7.2.3.3.1.4	What are the effects of modifying the colloidal state of clouds or fog at the boundary?	E	E	E	E	T	N	N	N	T	E	T	T	√	E	H	H	E	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A,B	NONE	√	√√
ATMOSPHERIC PROCESSES	6.7.2.3.3.2.1	What are the effects of changing the latent heat released by condensation and precipitation?	E	E	E	E	T	N	N	N	T	E	T	T	√	E	H	H	E	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A,B	NONE	√	√√
	6.7.2.3.3.2.2	What are the effects of modulating the reflection, absorption, and emission of radiation by the atmosphere or clouds?	E	E	E	E	T	N	N	N	T	E	T	T	√	E	H	H	E	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A,B	NONE	√	√√
	6.7.2.3.3.2.3	What are the effects of changing the aerosol (dust) field in the atmosphere?	E	E	E	E	T	N	N	N	T	E	T	T	√	E	H	H	E	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A,B	NONE	√	√√
	6.7.2.3.3.2.4	What are the effects of modifying the colloidal state of clouds over large areas?	E	E	E	E	T	N	N	N	T	E	T	T	√	E	H	H	E	E	H	H	H	H	H	T	NA	NA	NA	T	T	NA	√	A,B	NONE	√	√√

Consequently, many regions that are crucial in determining the weather of other areas are not under observation at all. For example, it has been estimated that only about 10 percent of the atmosphere is sufficiently observed with nonspace systems, and even here, many of these observations lack accuracy and consistency because of the use of dissimilar instruments.

Other important points have been briefly stated in the 1963 NAS/NRC report, "An Outline of International Programs in the Atmospheric Sciences," which reads as follows:

> The atmosphere is a physical system in which there exists important interactions between phenomena on all time and space scales, and between these phenomena and the underlying surface. It is generally conceded that atmospheric motions (that is, weather) are deterministic on the basis of knowledge of their spatial distribution at some initial time, the appropriate boundary conditions and given external conditions. On this basis, the future state of the atmosphere can be calculated from physical law only if the macro-scale dynamical and thermodynamical variables are defined initially, and if it is also possible to specify the effects of smaller-scale motions at the boundary of and within the atmosphere as a function of the macro-scale variables.
>
> Only when these conditions are satisifed will it be possible to predict with accuracy the future state of the atmosphere and to simulate it by mathematical models. A capability to simulate the atmosphere in this manner is necessary to test theories of atmospheric motions, and examine the consequences of 'controlled' variations of internal or external parameters on the future state of the system.

Current meteorological observational techniques can be characterized as requiring extensive research and development. The ability of satellite sensors to detect and measure with sufficient precision the parameters that are needed in meteorology for understanding and predicting atmospheric phenomena is at best very limited. For example, although there is a requirement for knowledge of the spatial and temporal distribution of pressure in middle and high latitudes, the satellite sensor cannot measure pressure with the precision required. The same is true for wind velocity, which is particularly important in the tropics.

Observational networks embrace areal scales that range from global to regional (areas approximately the size of a continent) to local (areas roughly a thousand miles on a side) and are quite arbitrary, reflecting a combination of phenomenological scales and organizational units (i.e., the World Meteorological Organization) for the collection and dissemination of the data. Thus, the observational tools, and particularly the satellite, must be capable of (1) making measurements on all three scales named above and with the sensitivity or resolution required by the scale of the phenomena, and (2) expeditiously transmitting the data to the user.

Another characteristic of meteorology is that it requires continuous monitoring because all observational phenomena are time-dependent, with lifetimes on the order of tens of minutes for local clouds and severe storms, such as tornadoes, to months and years for seasonal characteristics and climatic variations.

There is still another aspect of meteorological observations from space: they provide data that can be obtained in no other reasonable way. Such data include the overall view of detailed cloud patterns associated with many different types of weather conditions and systems. The full information that can be deduced from these pattern details, however, remains to be determined.

In the light of the above discussion, and recognizing the viability and the achievements of the National Meteorological Satellite Program, it is not surprising that all groupings of critical issues are retained as being suitable for space.

Sufficient data points are available from the ongoing unmanned meteorological satellite program to indicate that space environment characteristics are of little or no effect, or that they are tolerable. The exception is atmospheric attenuation, which is considered essential. In meteorology, the attenuating properties and characteristics of the atmosphere permit the observation and measurement of phenomena (such as clouds, precipitation, aerosols, pollutants, and ozone) and of parameters (such as water vapor distribution, air motion field, and temperature field) that are important in resolving most critical issues.

In some cases, (e.g., where density may be duduced from measurements of stellar occultation, or where the vertical structure of the atmosphere is to be derived all the way to the surface), the presence of clouds or other aerosols in the sensor line of sight or field of view may limit the acquisition of information required by the critical issue. This undesirable effect is more than compensated, however, by the essentiality of the attenuation characteristic in meteorology.

As a result of the considerations discussed above, 46 of the 56 critical issues screened in Table 3-53 were deemed appropriate to space research.

3.7.8.2 Screening for Manned Space-Research Applicability

The 46 critical issues remaining in Meteorology were then screened as candidates for manned space research on the basis of criteria set forth in Subsection 3.7.1.3. This procedure assessed the participation of man, flight safety, and mission performance degradation.

An understanding of the role in man in space for meteorology starts with the assumption that a manned space research facility exists and carries special equipment for observing atmospheric phenomena. The participation of man is then examined on the basis of three fundamental types of interactions that man would have with the critical issues.

As a scientist-observer, man can play a significant role in the observation, description, and understanding of meteorological phenomena. His functions would be that of scientist-observer, development engineer and operator, and technician-serviceman.

The scientist-observer role is phenomenon-oriented and includes the selection, observation, and description of natural phenomena (programmed or unexpected) and two-way communication and cooperation with the ground. Both by visual observation and by the analysis and interpretation of analog data acquired by the ultraviolet, infrared, and microwave sensory systems under his control, man can detect, recognize, select, discriminate, analyze, interpret, and correlate various phenomena in a manner for which he is uniquely equipped by nature and by training. His ability to respond to objects of opportunity will be enhanced if he can have personal contact with the real-time flow of data. This assumes that proper onboard data displays will be available.

The scientist-observer role can also take advantage of the space research facility environment. Specifically, it has been proposed that cloud physics experiments in areas relating to phase transitions, particle capture coalescence, and charging be conducted in a zero-g environment, where it would be possible to study these effects without the perturbing influences that are built into experiments conducted to date in wind tunnels, cloud chimneys, or cloud chambers.* In the conduct of such experiments, a skilled experimenter would be needed. Such experimentation is critical to an understanding of the atmosphere's dynamic processes and is directly relevant to weather prediction and to weather modification and control.

The role of development engineer and operator is both phenomenon- and equipment-oriented. For certain targets, such as a newly discovered hurricane in the formative stage, high-resolution measurements will be needed of sea state, sea temperature, cloud structure and height, and the vertical and horizontal distribution of temperature, water vapor, and wind. From a moderately inclined, low-altitude orbit, there will be little chance of a second look during a subsequent orbit. Therefore, all of these measurements should be made simultaneously, and the sensors must be properly pointed during a relatively short path over the target. The operator role would also require making before-and-after measurement calibrations.

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*By Dr. C. L. Hosler, Pennsylvania State University

Thorough testing of instruments in actual space conditions for research and development purposes, and for later use in unmanned satellites, would be a natural role for the development engineer and operator. Here it is assumed that because of the size and available power of a manned space research facility, prototype equipment would not require miniaturization.

For example, in the early development stages of new instrumentation, when many design choices are available, a working breadboard could be installed on the spacecraft. The engineer-operator function would involve the manual operations, analyzing and discussing the data in two-way communication with ground personnel, and making modifications *in situ*. In advanced development phases, engineering shakedown and qualification testing would involve operation of the final device.

The role of man as a technician-serviceman is equipment-oriented, and for meteorology it is viewed from the standpoint of man's ability to assemble, position, calibrate, and align equipment, both initially (following launch) and at regular intervals thereafter. This role is also examined, for example, on the basis of man's ability to maintain and repair equipment, as well as to retrieve and replace equipment in an extravehicular activity mode. This role for man has little research orientation, but functionally it permits him to operate as a researcher in space.

Much of the analysis of the criteria relating to the participation of man in space in Meteorology amounts to subjective judgment regarding the degree of technical sophistication that may be required and justified to replace man's functions by unmanned automatic or ground-controlled systems, and to match his flexibility. If, for example, a camera must be switched on and off at given times, the required sophistication of an unmanned system is small. If, on the other hand, lighting discharges are to be detected and subsequently monitored visually and photographically, the complexity of a properly programmed unmanned system may be prohibitive. If an instruments's mechanical component has to be repaired or replaced, the required sophistication would almost certainly be prohibitive.

In analyzing specific criteria relating to man's participation in space research on the basis of the critical issues for Meteorology, there appears to be no reason for his not being there. For the most part, it is evident that man can play a significant role in space for Meteorology. The need for man does not appear to be absolute, however; rather, it seems that his participation will more efficiently and effectively satisfy the long-range scientific and technological goals for Meteorology and the critical issues that derive from them.

The Manned Space Flight criteria related to flight safety and mission performance have been discussed in Subsection 3.7.1.3 and are tabulated in Table 3-53. Based on previous experience in manned earth-orbital missions, the environmental extremes of space are considered tolerable. None of the critical issues are considered to require measurements that will either exceed physiological limits, cause excessive physiological stress, or affect crew safety.

Acceleration disturbances brought about by crew mobility are considered tolerable, as are the effects of the release of effluents. In the latter case, however, protection must be afforded to optical frontal elements during nonmeasurement periods. At the present time, there appears to be no requirement for any grouping of critical issues for repetitive duty cycles that would require continuous, high-precision observations with man constantly involved.

Summarizing the foregoing analysis, it is apparent that man in space can make significant contributions to the long-range goals for Meteorology. For the most part, man emerges as being potentially useful, although not essential. There are no critical issues where man's presence is intolerable, nor are there any flight safety or mission performance degradation criteria that appear to be intolerable. As a result, all 46 critical issues in Meteorology that were analyzed for manned research in space were retained, as shown in Table 3-53.

3.7.8.3 Contributions of Ongoing Programs

The critical issues in Meteorology that were selected as candidates for manned space research were next analyzed for the contributions of ongoing programs on the basis of criteria set forth in Subsections 3.7.1.4. This included a review of past and ongoing ~~space~~ programs relating to Meteorology, and a determination of ~~the~~ degree to which they satisfy the requirements of the critical issues.

The programs considered relate to the NASA Manned Space Flight Program and the National Meteorological Satellite Program. The former includes the Mercury, Gemini, and Apollo Programs, and the latter includes the NASA Research and Development Satellite and the ESSA Operational Meteorological Satellite.

It appears that all of the meteorological satellite programs are or will be examining many of the critical issues in Meteorology. However, meteorological research is open ended with new questions arising as knowledge is advanced and insight is improved. Although the relationship of ongoing programs to the critical issues is generally very close, they do not completely satisfy any of the research objectives, and therefore, none of the Meteorology critical issues were removed, as shown in Table 3-53.

3.7.8.4 Grouping of Critical Issues by Experimental Approach

In view of the 10-year head start that meteorology has gained by virtue of a successful unmanned program, it is believed that the experimental approaches that would best evolve in the manned program are those that (1) contribute to the critical issue list in the broadest possible sense, (2) capitalize on man's presence, and (3) are not likely to be accomplished, at least in the foreseeable future, by unmanned systems. Consequently, six research clusters have been identified as candidates for the earth-orbital experiment program. They are listed in Table 3-54, together with their applications and the specific research categories of critical issues to which they are applicable. Worthy of note is the breadth of applicability to the research categories in Meteorology.

3.7.8.5 Brief Descriptions of the Research Clusters

In summary, in the subdiscipline of Meteorology, six research clusters were formed from the 46 critical issues judged to be suitable for a manned earth-orbital research program. A brief description of these research clusters is included in the series of synopses of the seven subdisciplines of Earth Observations, which follow. More detailed descriptions may be found in Appendix C.

TABLE 3-54

RESEARCH AREAS FOR EARTH-ORBITAL EXPERIMENT PROGRAM--METEOROLOGY

Research Cluster		Application	Chemical State	Physical State	Circulation State	Change of State	Prediction of Future State	Modifications and Control
		Specific Research Categories of Critical Issues						
6-M-1	Determination of Boundary Layer Exchange Processes Using IR Radiometry.	Exchange of momentum, heat, and moisture at terrain-atmosphere interface and lowest atmospheric layer.		X	X	X	X	X
6-M-2	UHF Sferics Detection	Study of convective and electrical activity in severe storms	X	X	X	X	X	X
6-M-3	Atmosphere Density Measurements by Stellar Occulation	Measurement of spatial and temporal distribution of atmospheric density	X	X	X	X	X	X
6-M-4	Zero-G Environment Cloud Physics Experiment	Understanding of cloud dynamics to be obtained	X	X		X	X	X
6-M-5	Detection and Monitoring of Atmospheric Pollutants	Monitoring of the global distribution of atmospheric contaminants	X	X	X	X	X	X
6-M-6	Support of Studies of Special Geographical Areas	Support of GARP and other programs (i. e., arctic heat-budget study)		X	X	X	X	X

SUBDISCIPLINE SYNOPSIS

6-EP

Earth Physics

1. Research Objectives

The objectives of this group of research clusters are-

6-EP-1 Generate and update geotectonic maps of the earth's surface with a resolution of < 500 meters, to determine:

(A) The present shape, state and position of the earth's land masses, ocean basins and polar ice sheets;

(B) The relative drifts of continental land masses, major fault systems, water and ice surfaces.

6-EP-2 Locate and map active tectonic and volcanic belts to determine:

(A) Times of occurrence of activity, duration, periodicity/aperiodicity and intensity of heat buildup and decline;

(B) Relationships between submarine volcanic activity and tsunami location and intensity.

2. Background and Current Status

Limited photography of certain regions of the U.S., notably from the Apollo 6, 7, and 9 missions, has demonstrated the value of observations from space in the compilation of geotectonic and geomorphological maps. Thermal infrared imagery from NIMBUS has been used successfully for observations of active volcanoes. An extension of these techniques to provide repetitive synoptic coverage at higher latitudes and - in the case of infrared data - with better resolution, is required for these research clusters; instrumentation using state-of-the-art techniques can be developed to meet these requirements.

3. Description of Research

To meet the need for better geotectonic, geomorphological and volcanic/geothermal source data, orbital research is required to optimize the generation of geological maps from metric and multispectral cameras and thermal infrared sensors.

4. Impact on the Spacecraft

Precise location of geologic and volcanic features requires knowledge of spacecraft ephemeris, altitude and attitude, to enable location of the optical axis subpoint to < 500 meters relative to ground control points. A polar sun-synchronous orbit is required to fully meet the requirements of these research clusters. Crew functions would include location of cloud-free areas; selection and operation of the tracking telescope, cameras, infrared sensors, film and filters and correlation of images and prior map data.

5. Required Supporting Technology Development

Requirements for these research clusters include:

(A) Advanced techniques for precise determination of spacecraft ephemeris, altitude, attitude and optical axis orientation;

(B) Development of a high resolution multiband infrared imager;

(C) Development of variable magnification telescope for surface viewing.

SUBDISCIPLINE SYNOPSIS
6-A/F
Agriculture/Forestry

1. Research Objectives

The major objective of these research clusters is to evaluate and demonstrate the potential of a manned space platform in the gathering of data used by the U.S. Department of Agriculture and others: the data is used in developing statistics, maps and similar tools for the management of agriculture, forest and range resources. Research will be done in the following areas:

- 6-AF-1 Location and acreage of present and future cultivated, forested, and ranged lands;
- 6-AF-2 The remote determination of soil type and quality, such as moisture, salinity, organic content and friability;
- 6-AF-3 The remote identification of food, fiber and wood species for inclusion in the statistical data or maps developed under 6-AF-1;
- 6-AF-4 Estimates of the size, vigor and projected yield of crops, from

which crop forecasts can be made (this research will include transient stress induced by disease or insect infestation, and chronic stress induced by longer-duration factors such as drought, saline water encroachment or atmospheric pollution);

6-AF-5 Feasibility and advantages of a wildfire-fighting system that adapts the present airplane techniques to space for the detection of incipient fires, the tracking of active fires, and the determination of flammability index.

2. Background and Current Status

The Department of Agriculture annually surveys about 200 million acres (~ 20 percent) of the USA, using aerial photography. Forest fire surveillance is done by overflights of potentially hazardous areas by the Forest Service and local (state and county) authorities. Gemini and Apollo 9 multiband photography has demonstrated the potential for orbital observations and discrimination of crop, range, and timber boundaries. Recent ITOS and NIMBUS infrared imagery is being studied to ascertain if the major forest fires that occurred in Southern California in September 1970 are detectable from space. When combined with the automated data processing techniques (such as those developed by USDA/University of Purdue, Colwell/UC Berkeley, and others) the near orthophotographic quality of orbital imagery promises to provide more complete and timely information to the agronomists than do the current ground and airplane techniques. Thus, the sensor and data processing programs have demonstrated not only the feasibility of the remote identification of gross land use (such as timber from cultivated crops), but also the feasibility of discriminating crop and timber species and the presence of stress. Future development of these recognition and discrimination techniques for agricultural resources inventory and management requires (1) continued research in sensors and sensing techniques from orbital, airborne, and ground-based platforms and (2) research in automatic data retrieval and display.

3. Description of Research

The U.S. Department of Agriculture currently is doing research on all of the research objectives, but the results often are hampered by the limited surveys that are possible by ground and airplane observations. Metric cameras using broad-band color films will photograph large areas of the earth for use in defining gross land use. Multispectral cameras will be used to identify types of vegetation, vigor and yield of sample areas within a given land use area. The astronaut will experiment with such items as films, filters, exposure, and cloud cover to determine those combinations that produce the best data for a given observation. A photo development and analysis capability should be provided aboard the space platform. Extended to space will be the species identification research that has been done using an airplane-borne multispectral scanner. The spacecraft also will carry a spectrometer and radiometer that can be trained on specific targets by the astronaut. Initially, these sensors will be trained on controlled plantings at truth sites to determine the spectral signatures from space of vegetation, soil types, and soil quality. Radar imager data also will be taken over these truth sites. Once the signatures have been established, the research will be extended to areas of general vegetation cover.

4. Impact on Spacecraft

The land use mapping will be done throughout the world, but the initial crop species and soil series research will be done over truth sites that are concentrated in the United States. To cover the major agricultural areas requires an orbit inclination of at least 55^{o} with a polar sun-synchronous orbit desired if northern Europe is included. The orbit altitude should be as low as aerodynamic drag reduction of life time will permit, and not above 275 miles. Additionally, to meet ground truth site and polarization experiment requirements, a rapid slew capability of 5^{o}/minute in roll and a conical scan capability of $\pm 60^{o}$ are desirable. Also a requirement is precise knowledge of the location of the optic axis subpoint to ± 30 meters. The development of wildfire detection techniques ideally requires operation from a geostationary orbit. A ΔV capability for orbital altitude change to provide diurnal coverage of areas of high flammability index can aid in the development of remote sensing techniques for wildfire detection and monitoring.

5. Required Supporting Technology Development

Requirements for these research clusters include:

(A) Techniques for accurate determination of spacecraft ephemeris, altitude, and attitude, and optical axis orientation for the precise measurements required for soil quality identification;

(B) Additional and improved signature recognition techniques for automated identification, recognition, and classification of vegetation type, vigor and yield, and soil types and quality;

(C) Development of a multispectral imaging telescope with interchangeable spectrometer and radiometers capable of being trained on small targets by the astronaut;

(D) Spectral, spatial, and temporal signatures of vegetation species and vigor and of soil type and quality as related to solar illumination, degree of maturity, atmospheric properties and season;

(E) Development of infrared and microwave imagers, spectrometers and radiometers that have temperature resolution of 0.5^{o}K and spatial resolution of less than 10 meters.

SUBDISCIPLINE SYNOPSIS
6-G/C
Geography/Cartography
6-G
Geology

1. Research Objectives

This group of research clusters is directed towards the following objectives:

6-G/C-1 Provide a precise and accurate geometric description of the earth's surface;

6-G-1 Determine the performance of remote sensors in the identification, location and distribution of rock and soil types;

6-G-2 Identify regions remote from population centers which may be suitable for storage or disposal of waste materials, including recognition of drainage patterns, karst topography and soil types;

6-G-3 Monitor and predict geological hazards and disasters, and establish a realtime warning capability;

6-G-4 Determine how remote sensors might locate new geothermal power sources and establish the spectral signature criteria relevant to detection, identification, and classification of these sources;

6-G-5 Detect geological characteristics indicative of mineral or oil deposits, including anticlines, synclines, domes, igneous intrusions, and hydrothermal zones;

6-G-6 Identify landforms and structural forms, using the techniques proposed to meet the objectives of 6-G/C-1.

2. Background and Current Status

Less than 20 percent of the earth's land mass is currently mapped topographically at scales suitable for earth resources research. Orbital photography and multisensor/multispectral imagery can provide near-orthophotographic quality data repetitively at any desired scale to meet the research objectives called out above. The Apollo 9 color photography of the Tucson, Arizona and Dallas-Fort Worth, Texas areas already has demonstrated on a limited scale that space photography can define the transportation network and the boundaries of urban areas, as well as their changes with time, and can classify the principal geological and land use characteristics. Aircraft flights of infrared and microwave radar imaging systems have demonstrated the feasibility of identifying landforms and structural forms in otherwise inaccessible areas. Aircraft and balloon flights of correlation spectrometers have demonstrated the feasibility of detecting space elements, such as mercury, indicative of significant mineral deposits. Ground-based experiments in rock type classification, using multispectral infrared scanners, have shown the feasibility of discriminating between differing rock types; in this case, experiments used the infrared signatures of the different rock types.

Extension of these techniques to orbital altitude, and optimum use of man's ability to correlate regional tonal change in the visible spectrum with data acquired at other wavelengths and with his own geological experience will lead to a significant acceleration in the acquisition and compilation of required new data. Current limitations in capability beyond the visible spectrum arise from the poor spectral or spatial resolution currently available from infrared or microwave sensors at orbital altitude. Similarly, adequate ground control data, on a global scale (particularly over the oceans and at high latitudes, required to provide a better understanding of the geometry and changes of the earth's surface) requires the development of improved instrumentation; this includes more precise ephemeris determination and laser ranging techniques for surface contouring.

3. Description of Research

The primary goal of this research program is to develop and evaluate techniques and instruments for improved observation and monitoring, from orbital altitude, of geodetic and geological phenomena which may influence planning and management of geological resources on a global scale. Of the many techniques currently proposed for these observations, the optimum combination is to be determined through the use of multipurpose instrumentation and trained astronauts who can selectively integrate data acquired from orbital altitude.

4. Impact on Spacecraft

To meet the requirements of this group of research clusters, the following criteria must be satisfied:

(A) Determine the optical axis subpoint location to an accuracy of a few meters;

(B) Orient and boresight all sensors with a 60° cone angle for specific ground truth site and polarization measurements, with a maximum slew rate of 5°/minute;

(C) Provide data processing and display equipment to enable the observer/experimenter to make onboard decisions relative to instrument selection and configuration;

(D) Provide sufficient ΔV capability to allow orbital altitude to be changed within the range of 80 to 300 nmi to accommodate illumination and overlap/underlap requirements.

5. Required Supporting Technology Development.

Needed are: advanced sensor development (including a multipurpose tracking telescope for use at visible and infrared wavelengths), high resolution channel multipliers and thermal infrared detector arrays, scanning correlation spectrometers, multifrequency electronically-scanned microwave antennas and precision pointing, ranging, and measurement systems.

SUBDISCIPLINE SYNOPSIS

6-H

Hydrology

1. Research Objectives

The objective of this group of research clusters can be summarized as follows:

- 6-H-1 Determination of the feasibility of sensing pollution of water resources from orbital altitude using photographic, multispectral and spectrophotometric sensors;
- 6-H-2 Determination of the scope and configuration of a spaceborne and user-oriented flood warning and damage assessment system;
- 6-H-3 Evaluation of a complete data system for better utilization of the world's water resources and improved understanding of the global water budget;
- 6-H-4 Provision of information on snow and ice inventory and temporal changes in snow and ice pack cover required to improve and verify models of the hydrological cycle and weather prediction;
- 6-H-5 Identification of the distinguishing spectral, spatial, and temperature characteristics of soil moisture and the areal distribution/seasonal variation of the liquid and frozen states;
- 6-H-6 Identification of the distinguishing spectral, spatial, and temporal characteristics of significant geological and geographical features that relate to underground water resources;
- 6-H-7 Evaluation of the potential operational use of spacecraft to provide information on topographical features which may influence water system management.

2. Background and Current Status

The synoptic coverage obtainable from orbital altitude, when complemented by a data collection system to acquire data from ground-based sensors, can provide repetitive large-scale measurements of the location, and dispersion mechanisms associated with fresh water resources. Hydrological observations from orbit have so far been limited to snow and ice field mapping from ESSA, NIMBUS, and ITOS, together with studies of drainage patterns and surface water inventory using Gemini and Apollo photography. Improved multispectral photography, infrared, radar, and passive microwave imagery is expected to provide better data for hydrological research and operations.

3. Description of Research

Initial observations will be made over those sites (such as Lake Michigan and the Chesapeake Bay) previously and concurrently surveyed in the NASA/MSC aircraft program, which are of specific interest in pollution detection and monitoring studies. The aim of this research is to evaluate and optimize the instrumentation to be used in an operational hydrological monitoring system. Spatially correlated data from cameras, line scanners, and microwave instruments would be compared in near-realtime with ground-based measurements and observations.

4. Impact on Spacecraft

Pointing capability within a 60° cone at maximum rate of 5°/minute is needed to meet the requirements of this group of research clusters (including cooperative operation with widely dispersed ground truth sites). A polar sun synchronous orbit is desirable to meet the requirements for snow and ice field mapping. Because of the combined extremely high data rates and data redundancy, crew participation in onboard data processing and compaction is necessary and desirable. Needed to support this activity are data storage, readout, and processing equipment, along with a film development and analysis facility.

5. Required Supporting Technology Development

Onboard film processing and analysis equipment; a multipurpose telescope with interchangeable spectrophotometer and spectroradiometer heads and multifrefrequency active and passive microwave systems.

SUBDISCIPLINE SYNOPSIS

6-0

Oceanography and Marine Resources

1. Research Objectives

The primary objectives of this group of research clusters are:

(A) Evaluate and develop instrumentation and techniques for synoptic observations of the oceans and coastal regions;

(B) Develop data acquisition and processing techniques to provide improved data for the ocean and coastal models.

The principal experimental areas and the research to be performed to meet these objectives are as follows:

6-0-1 Increase knowledge of the effects of pollution on the physical, chemical, and biological processes of the ocean;

6-0-2 Improve understanding of the partition of energy between the sun, ocean, and atmosphere, and the effects of winds, currents, turbidity, and weather on this partition;

6-0-3 Improve understanding of the ocean population dynamics to determine and improve the maximum sustainable yield of the world's fisheries;

6-0-4 Improve knowledge and forecasts of the ocean currents, tides and upwelling, including more information of the variations in height of the sea surface relative to the equipotential surface;

6-0-5 Improve knowledge of the physical and chemical proerties of the ocean, in particular the density, salinity, and temperature distributions;

6-0-6 Improve knowledge of the processes that change the character and shape of the coastlines and the adjacent sea bottom.

2. Background and Current Status

Space photography of the oceans and coastal regions has already demonstrated the potential for monitoring such phenomena as:

(A) Sea stae

(B) Current boundaries

(C) Sedimentation and pollutant transportation

(D) Coastal erosion processes

(E) Regions of upwelling, indicative of fish feeding grounds

Extension of these observations, leading to development of a global operation capability, can use several instruments currently available or under study. Examples of these include metric, panoramic, and multispectral cameras, infrared scanners, and passive microwave radiometers. For operation in regions normally covered by clouds, there is a need for development and evaluation of improved microwave radiometers and radar scatterometers having large equivalent apertures. As in other experiment areas in earth observations, instrument combinations need to be optimized and techniques developed to strip out the vast amount of redundant data inherent in ocean observations. Quantitative monitoring of water pollutants may require a significant improvement in spectral resolution of spectrophotometers and spectroradiometers, and possibly the development of a swept-frequency lidar system. A laser altimeter is also required to measure mean sea surface height.

3. Description of Research

Of the many parameters that are used for <u>in-situ</u> investigations of ocean characteristics, only color, surface roughness, relative albedo, temperature, and indirect effects on spectral reflectivity and emissivity appear to be immediately useful for remote observations. Many coastal processes are amenable to color and false color photographic or radar observation. The purpose of this research program is to evaluate and develop optimum instrument performance parameters and combinations.

4. Impact on Space Station

To perform all experiments currently identified, ten sensors weighing about 2,000 pounds and consuming 4,000 watts are proposed. Roughly one-half of the weight and power requirements are for the microwave radar imager used for sea ice observation. Maximum data rate is about 3M-bits/sec from the thermal band of the multispectral scanner and the ocean color sensor. The orbit altitude should be less than 250 miles and the inclination greater than 50 degrees. The signatures in general are not amenable to direct visual observation-except cloud, therefore, the primary role of man will be evaluation of the collected data for electronic quality and experimental usefulness. The special skill required is oceanographic; however, a meteorological skill also would be valuable because oceanography and meteorology are intimately related disciplines.

5. Required Supporting Technology Development

Research is required to better establish the signatures of the thermal, chemical, and biological properties of the ocean and how they vary with such factors as illumination, look angle, and surface roughness. A microwave radiometer scanner antenna (at least 15 feet in size) is required for research in surface roughness and temperature; a space-qualified radar imager with a resolution of 1 to 10 meters is required for research in ice surface characteristics.

SUBDISCIPLINE SYNOPSIS

Group 6-M

Meteorology

1. Research Objectives

The broad objective of these research clusters is to develop sensors and measurement techniques from space which will lead to improved numerical weather forecasting, weather modification, and climate control. Included also in these objectives is research in the detection of atmospheric pollutants and local severe storms, such as tornadoes.

6-M-1
6-M-6 Research Clusters M-1 and M-6 will investigate the potential for manned spacecraft to measure the temperature, moisture and cloud characteristics of the atmosphere from the surface through the stratosphere on a world-wide basis.

6-M-2 Research will be done relating the frequency and severity of sferic emissions from convective clouds to the occurrence of tornadoes and lightning-caused wildfires.

6-M-3 This cluster will research stellar occultation and microwave attenuation techniques for determining the density profile of the atmosphere in conjunctior with the temperature and moisture profiles of 6-M-1 and 6-M-6.

6-M-4 This cluster will perform cloud physics experiments in the near-zero gravity environment of space to substantiate and extend theories based on cloud chamber experiments done on the surface.

6-M-5 From a manned spacecraft, experiments will be performed on detecting and measuring the amount of pollutant gases in the underlying atmosphere.

2. Background and Status

Improvement in numerical weather prediction by ESSA and the eventual modification of weather requires better atmosphere models and more accurate data from a larger portion of the earth. Soundings of temperature, moisture, density, and the location of cells of severe convection are being made from the ground and from airplanes, and cloud cover is being monitored by meteorological satellites. However, needed in greater numbers are soundings of the atmosphere over the oceans, remote land areas, and the equatorial zone. Sensors and measurement technolgoy have been developed to the point that research can be undertaken on making these soundings from a manned space research facility.

Both Mercury and Gemini astronauts heard sferics on the UHF link, and thus systematic research will be undertaken relating these receptions to the presence of convection cells that might spawn tornadoes. This space research will be coordinated with the current US Department of Agriculture aircraft program to detect remotely the type of lightning that causes forest fires.

Using vertical wind tunnels and settling chambers, a great deal of research in cloud physics has been done by meteorologists in government, universities, and industry. Unfortunately, an environment not true to nature has been produced by the need to suspend the water droplets long enough to make observations. The nearly-zero gravity in space should allow observation of droplets for long periods without having to disturb the droplets by a supporting mechanism.

Air pollution research typically is restricted to local metropolitan areas, while the pollution problem is becoming Continent-wide in scope. A need is developing for periodic sampling of the atmosphere throughout an entire geographic area or an entire air mass. This is not practicable with aircraft, and a manned space vehicle promises to be a solution to rapid, wide-area coverage.

3. Description of Research

The spectral radiance of the atmosphere will be measured with spectrometers and radiometers having high spectral and temperature resolution. Measurements will be taken on the edges of the carbon dioxide absorption bands at 4.3 and 15 microns and the water absorption band at 6.3 microns. These sensors will make intermittent scans through the spectrum under the control of the scientist. He will set the scan interval, point the sensor at gaps in the clouds to observe the lower atmosphere, and choose different surfaces, such as soil, water, and clouds, for studying the effects of surface reflectance. The electronic quality of the data will be monitored onboard. The inversion of the radiance data into temperature and moisture profiles will be done on the ground.

The density profile is measured by stellar occultation and microwave attenuation. In the stellar occultation experiment, initial star acquisition will be performed manually. The pointing angles of the telescope and the position of the station are recorded and converted to density profiles by a computer program that relates bending of the star ray to density of the intervening atmosphere. The microwave experiment for density profiling uses two subsatellites carrying a calibrated transmitter or a receiver. The subsatellites are deployed by the crew. The attenuation of the signal from one subsatellite to the other by the intervening atmosphere is a measure of the density of the atmosphere.

Sferics research will consist of the space scientist selecting (probably in concert with a surface meteorologist) a likely weather system, pointing the sferics antenna at it, and monitoring the emissions. The scientist also will observe visible lightning bolts with a hand-held H α-line viewer, as well as cloud type, form, and amount, then will make a record of his observations and interpretations. These observations also are part of the fire-lightning research of the U.S. Department of Agriculture Forest Service and will require direct communication with the forest fire warning network.

For air pollution experiments the scientist in space will train an absorption spectrometer on areas of air pollution. A swath will be recorded across an area, such as the Los Angeles Basin, or across an air mass that recently has been over a pollution source. The astronaut also will select cloud-free areas and do research on the effects of various underlying reflective surfaces (such as rural, urban, and ocean) on the measurements. He will select standard absorption spectra masks for the particular gases he is seeking, and the spectrometer will correlate the observed spectra with the standard spectra. Correlation indicates the presence of the gas; the intensity of the signal is a measure of the amount of pollutant gas.

Cloud physics research will consist of introducing water droplets of selected sizes into a cloud chamber. The scientist will vary the temperature, electric field, and relative humidity of the chamber, and will record the results verbally and on still and motion pictures.

4. Impact on Space Station

The research in properties of the atmosphere could be done with a low inclination orbit, such as 30°; however, the pollution and sferics research requires coverage of the United States up to about 50 degrees. Though an altitude below 300 miles is satisfactory, the pollution research prefers 200 miles because the ground resolution element size is smaller. Power demands will be 200 watts for the cloud chamber, and 500 watts for the metric camera used to record cloud cover. Maximum data rate for any one sensor is about 40 kbits/sec. At least one astronaut trained in the meteorological sciences is required to select targets, choose [illegible] bands, and evaluate the "seeing". He should be supported by technicians skilled in electronics, optics, and cryogenics.

5. Required Supporting Technology Development

The basic sensor and technology has been developed by similar ground and aircraft programs. The general requirement is for manned space-qualified versions of the sensors that can be modified by an astronaut to fit the needs of a particular experiment at a particular time. A specific requirement is for an observation telescope with spectrometers and radiometers boresighted and slaved to it.

3.7.9 References for Section 3.7

3.7-1 Earth Orbital Experiment Program and Requirements Study: Scientific and Technological Objectives. Report No. L13-9852, NASA Langley Research Center, July 28, 1969.

3.7-2 Earth Surveys Program Documentation. Earth Surveys Planning Panel, October 22, 1969.

3.7-3 Space Applications Summer Study: 1967 Interim Report, Volume I. National Academy of Sciences, National Research Council, November 1967.

3.7-4 Useful Applications of Earth-Oriented Satellites, Volumes 1 through 13, National Academy of Sciences, National Research Council, 1969.

3.7-5 Earth Resources Satellite System, Report for the Subcommittee on NASA Oversight. Committee on Science and Astronautics, U.S. House of Representatives, 90th Congress, 1968.

3.7-6 Tellurian Resources Inventory and Development (TRIAD), Preliminary Design of an Operational Earth Resources Survey System. 1969 Summer Faculty Fellowship Program in Engineering Systems Design, ASEE-NASA Langley Research Center and Old Dominion University Research Foundation, 1969.

3.7-7 The Role of Manned Space Flight in the Earth Resources Program. NASA Earth Surveys Planning Panel, August 1969.

3.7-8 Candidate Experiment Program for Manned Space Stations. NASA document NHB 7150.XX, September 15, 1969.

3.7-9 Solid Earth and Ocean Physics. Report of the NASA Seminar, Williamstown, November 1969.

3.7-10 Our Nation and the Sea. Report of the Commission on Marine Science, Engineering and Resources, January 1969.

3.7-11 The Post-Apollo Space Program, Directions for the Future. The Space Task Group Report, September 1969.

3.7-12 Peaceful Uses of Earth-Observation Spacecraft. Volumes I, II and III, University of Michigan, NASA Contractor Report CR-587, September 1966.

3.7-13 Spacecraft in Geographic Research. Report of Conference at NASA Manned Spacecraft Center, Houston, Texas, January 28-30, 1965. Publication No. 1353, National Academy of Sciences National Research Council, Washington, D.C., 1966.

3.7-14 Agricultural Application of Remote Sensing-The Potential from Space Platforms. Agriculture Information Bulletin No. 328, Economic Research Service, U.S. Department of Agriculture, September 1967.

3.7-15 R. J. P. Lyon and E. A. Burns. Infrared Spectral Analyses of the Lunar Surface from an Orbiting Spacecraft. Proceedings of the Second Symposium on Remote Sensing of Environment, AD 299 841, University of Michigan, October 1962.

3.7-16 R. C. Wilson. Forestry and Range Applications of Remote Sensing Using Earth Orbital Spacecraft. Circa 1980, draft prepared for Forestry Remote Sensing Laboratory, University of California, Berkeley, September 1969.

3.7-17 The Use of Man in Space Observations. Bellcomm, Inc., October 1969.

3.7-18 Sensor Definition Study in Support of Unified Space Applications Mission (USAM). Prepared by Space Systems Center, International Business Machines Corporation, for NASA Goddard Space Flight Center, February 1968.

3.7-19 Proceedings of the AIAA Earth Resources Observations and Information Systems Meeting. Annapolis, Maryland, March 1970. Paper No. 70-312, Remote Sensors-A New Data Source for Agricultural Statistics, Earl E. Houseman, U. S. Dept. of Agriculture.

3.7-20 ORL Experiment Program. Volumes A, B, C, and D, prepared by Federal Systems Division, International Business Machine Corporation, Contract NASw-1215, 21 February 1966.

3.7-21 Oceanography and Meteorology, A Systems Analysis to Identify Orbital Research Requirements. Douglas Missiles and Space Systems Division, Report Nos. DAC-58120 and -58121, April 1968.

3.7-22 Conference with Dr. Robert H. Miller, Agricultural Research Service, U.S. Department of Agriculture, Washington, D.C.

3.7-23 Conference with Mr. G. A. Thorley, Consultant, Forestry Remote Sensing Laboratory, University of California, Berkeley, California.

3.7-24 Useful Applications of Earth-Oriented Satellites. Summaries of Panel Reports, National Academy of Sciences, National Research Council, 1969.

3.7-25 Statement of Mr. W. T. Pecora, Director of the U. S. Geological Survey.

3.7-26 Oral statement of Mr. W. T. Pecora, Director of the U. S. Geological Survey.

3.7-27 NASA Aircraft Project, Second Annual Program Review, September 16 to 18, 1969, NASA Manned Spacecraft Center, Houston, Texas.

3.7-28 Experiment Program for Extended Earth Orbital Missions. Vol. 1, Science and Applications, Earth Survey, NASA Washington, D.C., September 1, 1969.

3.7-29 Dianne Earing, et al. Target Signature Analysis Center, Data Compilation. AD 489-968, Infrared and Optical Sensors Laboratory, Willow Run Laboratories, Institute of Science and Technology, University of Michigan, July 6, 1966.

3.7-30 Orbital Astronomy Support Facility Study Final Report. Technical Summary, Douglas Report No. DAC-58141, April 1968.

3.7-31 Earth Surveys Program Documentation. NASA Headquarters, April 22, 1969

3.7-32 Earth Surveys Planning Panel, Meteorology Subpanel Documentation. NASA Headquarters, October 17, 1969.

3.7-33 J. O. Fletcher. The Heat Budget of the Arctic Basin and Its Relation to Climate. Report No. R-444-PR, the RAND Corporation, Santa Monica, California, 1965.

3.7-34 J. O. Fletcher. Proceedings of the Symposium on the Arctic Heat Budget and Atmospheric Circulation. Report No. RH-5233-NSF, The RAND Corporation, Santa Monica, California, 1966.

3.7-35 S. H. Dole, et al. Methodologies for Analyzing the Comparative Effectiveness and Costs of Alternative Space Plans. Vol. 1 (Summary Volume), Vol. 2 (Technical Volume), Report No. RM-5656-NASA, The RAND Corporation, Santa Monica, California, 1968.

3.7-36 NASA Authorization for Fiscal Year 1970. Hearings before the U. S. Senate Committee on Aeronautical and Space Sciences, 1969.

3.7-37 Global Atmospheric Research Programme (GARP). Report of the Study Conference held at Stockholm, ICSV/IVGG Committee on Atmospheric Sciences, June-July 1967.

3.7-38 Man's Geophysical Environment: Its Study from Space. A report prepared for the Administrator of ESSA, U.S. Department of Commerce, March 1968.

3.7-39 The Needs and Requirements for a Manned Space Station. Vol. 4, Meteorology, Panel on Meteorology of the Space Station Requirements Steering Committee, NASA, November 1966.

3.7-40 Weather and Climate Modification: Problems and Prospects. Volumes I and II, Final Report of the Panel on Weather and Climate Modification to the Committee on Atmospheric Sciences, NAS/NRC, Washington, D.C., 1966.

3.7-41 Status Report on the Application of Space Technology to the World Weather Watch. COSPAR Working Group VI, June 1967.

3.7-42 Atmospheric Exploration by Remote Probes. Volume [illegible], Proceedings of the Scientific Meetings of the Panel on Remote Atmospheric Probing, April - May 1968, to the Committee on Atmospheric Sciences, NAS/NRC, Washington, D.C., January 1969.

3.8 RESEARCH CLUSTERS

The culmination of the screening and grouping of critical issues in the six disciplines of the study was the establishment of 136 research clusters. Each research cluster represents a related body of research activity addressing a series of critical issues (i.e., important and timely research questions).

Complete descriptions of the research clusters are presented in Appendix C. Each description, in general, consists of (1) a narrative synopsis of the research cluster and (2) a list, by number and research question, of the critical issues addressed by the cluster.

Table 3-55 identifies the 136 research clusters by number and title.

TABLE 3-55 (page 1 of 8)

RESEARCH CLUSTERS

MANNED SPACE FLIGHT CAPABILITY

Cluster No.	Title
BIOMEDICINE	
1-BM-4*	Effects of Weightlessness on Circulatory Function
1-BM-5	Radiation, Toxicology, and Medical Problems
1-BM-6	Effects of Weightlessness on Stress Response
1-BM-7	Effects of Weightlessness on the Nervous System
1-BM-8	Effects of Weightlessness on Gastro-intestinal Function
1-BM-10	Body Fluid Analysis
1-BM-12	Studies on Instrumented Animals
1-BM-13	Effects of Weightlessness on Pulmonary Function
1-BM-14	Effects of Weightlessness on Metabolism
1-BM-15	Centrifuge Studies
BEHAVIORAL RESEARCH	
1-BR-1	Sensory, Psychomotor, and Cognitive Behavior (5 parts)
1-BR-1-1	Visual Experiment
1-BR-1-2	Behavior Effects of Acoustic Environment
1-BR-1-3	Psychomotor
1-BR-1-4	Cognitive Capability
1-BR-1-5	Orientation
1-BR-2	Group Dyanmics and Personal Adjustment
1-BR-3	Complex Task Behavior
1-BR-4	Skills Retention
1-BR-6	Performance Measurement
MAN-MACHINE RESEARCH	
1-MM-1	Controls and Displays
1-MM-2	Locomotion and Restraint

*Missing numbers were assigned to clusters that were later combined with others or eliminated.

TABLE 3-55 (page 2 of 8)

Cluster No.	Title
1-MM-3	Habitability
1-MM-4	Work/Rest/Sleep Cycles
1-MM-5	Performance Aids
LIFE SUPPORT AND PROTECTIVE SYSTEMS	
1-LS-1	Phase Change and Thermal Processes
1-LS-2	Material Transport Processes
1-LS-3	Atmosphere Supply Processes
1-LS-4	Water Management
1-LS-5	Water Electrolysis
1-LS-6	Food Management and Processes
1-LS-7	Atmosphere Purification Methods
1-LS-8	Life Support Monitoring and Control
1-LS-9	Waste Management
1-LS-10	Heat Transport Equipment
1-LS-11	Crew Equipment and Protective Systems
1-LS-12	Life Support System Maintenance and Repair
ENGINEERING EXPERIMENTS	
1-EE-1	Data Management
1-EE-2	Structures
1-EE-3	Stabilization and Control (3 parts)
1-EE-3-1	Drift Measurement of Gyroscopic Attitude Controls
1-EE-3-2	Disturbance Torque Measurements
1-EE-3-3	Biowaste Electric Propulsion
1-EE-4	Navigation and Guidance (4 parts)
1-EE-4-1	Onboard Laser Ranging
1-EE-4-2	Interplanetary or Translunar Navigation By Spectroscopic Binary Satellite
1-EE-4-3	Landmark Tracker Orbital Navigation
1-EE-4-4	Navigation/Subsystem Candidate Evaluation
1-EE-5	Communications

Cluster No.	Title
OPERATIONS EXPERIMENTS	
1-OE-1	Logistics and Resupply (2 parts)
1-OE-1-1	Space Logistics and Resupply
1-OE-1-2	Emergency and Rescue Operations
1-OE-2	Maintenance, Repair and Retrofit
1-OE-3	Assembly and Deployment
1-OE-4	Module Operations
1-OE-5	Vehicle Support Operations
SPACE BIOLOGY	
VERTEBRATES	
2-VB-1	Preliminary Investigations of Biological Processes, Using Primates and Small Vertebrates
2-VB-2	Intermediate Investigations of Biological Processes, Using Primates and Small Vertebrates
2-VB-3	Advanced Investigations of Biological Processes, Using Primates and Small Vertebrates
INVERTEBRATES	
2-IN-1	Preliminary Investigations of Biological Processes, Using Invertebrates
2-IN-2	Intermediate Investigations of Biological Processes, Using Invertebrates
2-IN-3	Advanced Investigations of Biological Processes, Using Invertebrates
PROTISTS AND TISSUE CULTURES	
2-P/T-1	Preliminary Investigations of Biological Processes, Using Unicellular Specimens (protists and tissue cultures)
2-P/T-2	Intermediate Investigations of Biological Processes, Using Unicellular Specimens (protists and tissue cultures)
2-P/T-3	Advanced Investigations of Biological Processes, Using Unicellular Specimens (protists and tissue cultures)
PLANTS	
2-PL-1	Preliminary Investigations of Biological Processes, Using Plants

TABLE 3-55 (page 4 of 8)

Cluster No.	Title
2-PL-2	Intermediate Investigations of Biological Processes, Using Plants
2-PL-3	Advanced Investigations of Biological Processes, Using Plants
SPACE ASTRONOMY	
OPTICAL	
3-OW	Optical Structure of Small Extended Sources
3-OB	High-Resolution Planetary Optical Imagery
3-OS	Optical (Faint Threshold) Surveys
3-OP	High Precision Stellar Photometry
3-SO	Optical Studies of the Solar Photosphere and Chromosphere
X-RAY	
3-XR	Precise Location, Size, and Structure of Known Discrete X-ray Sources, and Existence of Additional Unknown Sources
LOW FREQUENCY RADIO	
3-LF	Location and Properties of Discrete LF Radio Sources, and Structure and Properties of Diffuse Sources
SPACE PHYSICS	
PHYSICS AND CHEMISTRY LABORATORY	
4-P/C-1	Effect of the Space Environment on Chemical Reactions
4-P/C-2	Shape and Stability of Liquid-Vapor Interfaces
4-P/C-3	Boiling and Convective Heat Transfer in Zero-G
4-P/C-4	Effect of Zero-Gravity on the Production of Controlled Density Materials
4-P/C-5	Effect of Electric and Magnetic Fields on Materials
4-P/C-6	The Use of Zero-Gravity to Produce Materials Having Superior Physical Characteristics
4-P/C-7	Improvements of Materials by Levitation Melting
4-P/C-8	Effect of Zero-Gravity on the Production of Films and Foils
4-P/C-9	Effects of Zero-G on Liquid Releases, Size Distribution of Liquid Drops

TABLE 3-55 (page 5 of 8)

Cluster No.	Title
4-P/C-10	Capillary Flow in Zero-G
4-P/C-11	Behavior of Superfluids in the Weightless State
PLASMA PHYSICS LABORATORY	
4-PP-1	Spacecraft Environment Interaction
4-PP-2	Energetic Particle Dynamics in the Magnetosphere (3 parts)
4-PP-2-1	Use of Alkali Metal Clouds as a Space Diagnostic
4-PP-2-2	Use of Electron Beams as a Space Diagnostic
4-PP-2-3	VLF Wave Propagation
4-PP-3	Thermal Plasma in the Ionosphere and Magnetosphere (3 parts)
4-PP-3-1	(Essentially the same as 4-PP-2-1)
4-PP-3-2	(Essentially the same as 4-PP-2-3)
4-PP-3-3	RF Plasma Resonance Studies
4-PP-4	Auroral Processes (3 parts)
4-PP-4-1	(Essentially the same as 4-PP-2-1)
4-PP-4-2	(Essentially the same as 4-PP-2-2)
4-PP-4-3	(Essentially the same as 4-PP-2-3)
COSMIC RAY LABORATORY	
4-CR-1	Charge and Energy Spectra of Cosmic Ray Nuclear Component
4-CR-2	Energy Spectrum of High-Energy Primary Electrons and Positrons
4-CR-3	Energy Spectrum and Spatial Distribution of Primary Gamma Rays
4-CR-4	Long-Lived Heavy Isotopes in Cosmic Rays
4-CR-5	Antinuclei in Cosmic Rays
4-CR-6	Quarks (Stable Fractionally Charged Particles) in Cosmic Rays
4-CR-7	Unknown Particles in Cosmic Rays
4-CR-8	Characteristics of Albedo Particles Above 100 MeV
4-CR-9	Nucleon-Nucleon Cross-Sections at High Energies
4-CR-10	Spallation Cross-Sections at High Energies

TABLE 3-55 (page 6 of 8)

Cluster No.	Title
NOISE	
5-N-1	Terrestrial Noise Measurements
5-N-2	Noise Source Identification
PROPAGATION	
5-P-1	Ionospheric Propagation Measurements
5-P-2	Tropospheric Propagation Measurements
5-P-3	Plasma Propagation Measurements
5-P-4	Multipath Measurements
TEST FACILITIES	
5-TF-1	Space Deployment and Calibration
5-TF-2	Demonstration and Test
COMMUNICATIONS SYSTEMS	
5-CS-1	MM Wave Demonstration
5-CS-2	Optical Frequency Demonstration
NAVIGATION SYSTEMS	
5-NS-1	Satellite Navigation Techniques for Terrestrial Users
5-NS-2	Laser Ranging
5-NS-3	Autonomous Navigation Systems for Space
5-NS-4	Surveillance Systems
5-NS-5	Collision Avoidance System Techniques
5-NS-6	Search and Rescue Systems
EARTH OBSERVATIONS	
EARTH PHYSICS	
6-EP-1	Photographic Coverage of the Earth
6-EP-2	Identification of Volcanic Activity

TABLE 3-55 (page 7 of 8)

Cluster No.	Title
AGRICULTURE, FOREST, AND RANGE RESOURCES	
6-A/F-1	Crop Inventory and Land Use
6-A/F-2	Soil Type Mapping
6-A/F-3	Crop Identification
6-A/F-4	Crop Vigor and Yield Prediction
6-A/F-5	Wildfire Detection and Mapping
GEOGRAPHY, CARTOGRAPHY, AND CULTURAL RESOURCES	
6-G/C-1	Photographic and Multisensor Mapping
GEOLOGY	
6-G-1	Rock and Soil Type Identification
6-G-2	Use of Earth's Crust to Store and Condition Commodities or Waste
6-G-3	Geologic Disaster Avoidance
6-G-4	Utilization of Geothermal Energy Sources
6-G-5	Mineral and Oil Deposit Discovery
6-G-6	Identification of Land Forms and Structural Forms
HYDROLOGY AND WATER RESOURCES	
6-H-1	Determination of Pollution in Water Resources
6-H-2	Flood Warning and Damage Assessment
6-H-3	Synoptic Inventory of Major Lakes and Reservoirs
6-H-4	Synoptic Inventory of Snow and Ice
6-H-5	Survey of Soil Moisture in Selected Areas of the North American Continent
6-H-6	Location of Underground Water Sources in Selected Areas
6-H-7	Survey of Hydrologic Features of Major River Basins
OCEANOGRAPHY AND MARINE RESOURCES	
6-O-1	Ocean Pollution Identification, Measurement, and Effects
6-O-2	Solar Energy Partition and Heating in the Sea Surface Layer
6-O-3	Ocean Population Dynamics and Fishery Resources

TABLE 3-55 (page 8 of 8)

Cluster No.	Title
6-O-4	Ocean Currents and Tide Forecasting
6-O-5	Ocean Physical Properties
6-O-6	Ocean Solid Boundary Processes
6-O-7	Ocean Surface Activity Forecasting
METEOROLOGY	
6-M-1	Determination of Boundary Layer Exchange Processes Using IR Radiometry
6-M-2	UHF Sferics Detection
6-M-3	Atmosphere Density Measurements by Stellar Occultation
6-M-4	Zero-G Environment Cloud Physics Experiment
6-M-5	Detection and Monitoring of Atmospheric Pollutants
6-M-6	Support of Studies of Special Geographical Areas

Section 4

RESEARCH CLUSTER DESCRIPTIONS

By means of the organized overviews in Appendix A, and discussed in Section 2 of this report, it is possible to trace from a central NASA objective through a structure of subobjectives to relevant critical issues. These critical issues essentially describe the requirements for research activities which, when accomplished, will satisfy the hierarchy of objectives and subobjectives. It is possible, therefore, to examine their impact in terms of the objectives and NASA goals that would be fulfilled by conducting various research activities. The screening processes discussed in Section 3 of this report categorize critical issues in terms of the research activities that can be undertaken by manned space systems.

During the study, 136 research clusters were examined in detail to describe the functional and operational characteristics of the experimental activities required to support the research involved in the individual clusters. This descriptive process was required to translate scientific research requirements into engineering requirements in terms of equipment and apparatus needs, electrical power demands, volumetric requirements, local environmental demand, and man-machine relationships. Table 4-1 lists the research clusters and identifies them by title and reference code designations.

The first digit of the code used in identifying the research clusters relates to the scientific or technology discipline as follows:

1. Manned Spaceflight Capability.
2. Space Biology.
3. Space Astronomy.
4. Space Physics.
5. Communications and Navigation.
6. Earth Observations.

Within each scientific or technology discipline, an additional sublevel of categorization was made in accordance with established scientific and technological subobjectives as identified in the organized overviews. The one- or two-letter codes which follow the discipline numbers are as follows:

1-BM-	Biomedicine
1-BR-	Behavioral Research
1-MM-	Man-Machine Research
1-LS-	Life Support and Protective Systems
1-EE-	Engineering Experiments
1-OE-	Operations Experiments
2-VB-	Vertebrates
2-IN-	Invertebrates
2-P/T-	Protists and Tissue Cultures
2-PL-	Plants
3-OW	Optical Fine-Structure Observations
3-XR	X-Ray Source Observations
3-LF	Low-Frequency Radio Observations
3-OB	Planetary Observations
3-OS	Optical Surveys
3-OP	High-Precision Stellar Photometry
3-SO	Optical Studies of the Solar Photosphere and Chromosphere
4-P/C-	Physics and Chemistry Laboratory Experiments
4-CR-	Cosmic-Ray Research
4-PP-	Plasma Physics Investigations
5-N-	Noise Studies
5-P-	Propagation Investigations
5-TF-	Communication Test Facility Investigations
5-CS-	Communication System Experiments
5-NS-	Navigation System Experiments
6-EP-	Earth Physics Applications
6-A/F-	Agriculture-Forestry Applications
6-G/C-	Geography and Cartography Applications
6-G-	Geology Applications
6-H-	Hydrology Applications
6-O-	Oceanography Applications
6-M-	Meteorology Applications

Detailed experiment analysis was not done for 1-BR-6, 1-LS-8, 1-LS-12, 1-EE-1, 1-EE-2 and 1-OE-2, since their information needs were found to be satisfied by data from experiments in other research clusters and contributions of on-going programs. In the cases of 3-OP and 3-SO, it was believed premature to prepare detailed experiment descriptions until operational experience has been gained in the currently scheduled Apollo Telescope Mount (ATM) solar observation program and with the Orbital Astronomy Observatory (OAO) measurements concerned with the absolute photometry of objects. It was recognized, however, that these research clusters represent viable areas of activity for future space astronomy missions and relate to a number of critical issues. Therefore, for completeness of reporting, synopses were prepared, with the suggestion that the descriptive details be expanded when the results of currently scheduled programs become available.

It should also be noted that because of the commonality observed among the parameters to be measured and the instruments required in cosmic-ray physics, a single experiment description was believed to be sufficient for the ten research clusters documented in this research area.

The first step of the analytic process consisted of describing, in qualitative and quantitative terms, the details of the research clusters stated in the paradigms of the discipline. This step took into account scientific methods and alternative theoretical or empirical methods of achieving the results (or data) that will yield, completely or in part, the information required of the research cluster. The second step of the process described research clusters in terms of experimental apparatus, equipment, resources, necessary onboard human skills, and requirements for supporting research and technology factors. These products of the second study process are necessary to establish engineering definitions of the interfaces between the experiments and the host space-platform or space-system elements

The following pages summarize the research facility requirements derived from an analysis of the research clusters appearing in Appendix C. Selected orbit parameters (inclination and altitude), spacecraft subsystem interfaces, data

Table 4-1 (Page 1 of 8)

RESEARCH CLUSTER MASTER LIST

RESEARCH CLUSTERS

MANNED SPACEFLIGHT CAPABILITY

Cluster No.	Title
BIOMEDICINE	
1-BM-4*	Effects of Weightlessness on Circulatory Function
1-BM-5	Radiation, Toxicology, and Medical Problems
1-BM-6	Effects of Weightlessness on Stress Response
1-BM-7	Effects of Weightlessness on the Nervous System
1-BM-8	Effects of Weightlessness on Gastro-intestinal Function
1-BM-10	Body Fluid Analysis
1-BM-12	Studies on Instrumented Animals
1-BM-13	Effects of Weightlessness on Pulmonary Function
1-BM-14	Effects of Weightlessness on Metabolism
1-BM-15	Centrifuge Studies
BEHAVIORAL RESEARCH	
1-BR-1	Sensory, Psychomotor, and Cognitive Behavior (5 parts)
1-BR-1-1	Visual Experiment
1-BR-1-2	Behavior Effects of Acoustic Environment
1-BR-1-3	Psychomotor
1-BR-1-4	Cognitive Capability
1-BR-1-5	Orientation
1-BR-2	Group Dynamics and Personal Adjustment
1-BR-3	Complex Task Behavior
1-BR-4	Skills Retention
1-BR-6	Performance Measurement

*Missing numbers were assigned to clusters that were later combined with others or eliminated.

MAN-MACHINE RESEARCH

1-MM-1	Controls and Displays
1-MM-2	Locomotion and Restraint
1-MM-3	Habitability
1-MM-4	Work/Rest/Sleep Cycles
1-MM-5	Performance Aids

LIFE SUPPORT AND PROTECTIVE SYSTEMS

1-LS-1	Phase Change and Thermal Processes
1-LS-2	Material Transport Processes
1-LS-3	Atmosphere Supply Processes
1-LS-4	Water Management
1-LS-5	Water Electrolysis
1-LS-6	Food Management and Processes
1-LS-7	Atmosphere Purification Methods
1-LS-8	Life Support Monitoring and Control
1-LS-9	Waste Management
1-LS-10	Heat Transport Equipment
1-LS-11	Crew Equipment and Protective Systems
1-LS-12	Life Support System Maintenance and Repair

ENGINEERING EXPERIMENTS

1-EE-1	Data Management
1-EE-2	Structures
1-EE-3	Stabilization and Control (3 parts)
1-EE-3-1	Drift Measurement of Gyroscopic Attitude Controls
1-EE-3-2	Disturbance Torque Measurements
1-EE-3-3	Biowaste Electric Propulsion
1-EE-4	Navigation and Guidance (4 parts)
1-EE-4-1	Onboard Laser Ranging
1-EE-4-2	Interplanetary or Translunar Navigation By Spectroscopic Binary Satellite

Cluster No.	Title
1-EE-4-3	Landmark Tracker Orbital Navigation
1-EE-4-4	Navigation/Subsystem Candidate Evaluation
1-EE-5	Communications
OPERATIONS EXPERIMENTS	
1-OE-1	Logistics and Resupply (2 parts)
1-OE-1-1	Space Logistics and Resupply
1-OE-1-2	Emergency and Rescue Operations
1-OE-2	Maintenance, Repair and Retrofit
1-OE-3	Assembly and Deployment
1-OE-4	Module Operations
1-OE-5	Vehicle Support Operations
SPACE BIOLOGY	
VERTEBRATES	
2-VB-1	Preliminary Investigations of Biological Processes, Using Primates and Small Vertebrates
2-VB-2	Intermediate Investigations of Biological Processes, Using Primates and Small Vertebrates
2-VB-3	Advanced Investigations of Biological Processes, Using Primates and Small Vertebrates
INVERTEBRATES	
2-IN-1	Preliminary Investigations of Biological Processes, Using Invertebrates
2-IN-2	Intermediate Investigations of Biological Processes, Using Invertebrates
2-IN-3	Advanced Investigations of Biological Processes, Using Invertebrates
PROTISTS AND TISSUE CULTURES	
2-P/T-1	Preliminary Investigations of Biological Processes, Using Unicellular Specimens (protists and tissue cultures)

Table 4-1 (Page 4 of 8)

Cluster No.	Title
2-P/T-2	Intermediate Investigations of Biological Processes, Using Unicellular Specimens (protists and tissue cultures)
2-P/T-3	Advanced Investigations of Biological Processes, Using Unicellular Specimens (protists and tissue cultures)
PLANTS	
2-PL-1	Preliminary Investigations of Biological Processes, Using Plants
2-PL-2	Intermediate Investigations of Biological Processes, Using Plants
2-PL-3	Advanced Investigations of Biological Processes, Using Plants
SPACE ASTRONOMY	
OPTICAL	
3-OW	Optical Structure of Small Extended Sources
3-OB	High-Resolution Planetary Optical Imagery
3-OS	Optical (Faint Threshold) Surveys
3-OP	High Precision Stellar Photometry
3-SO	Optical Studies of the Solar Photosphere and Chromosphere
X-RAY	
3-XR	Precise Location, Size, and Structure of Known Discrete X-ray Sources, and Existence of Additional Unknown Sources
LOW FREQUENCY RADIO	
3-LF	Location and Properties of Discrete LF Radio Sources, and Structure and Properties of Diffuse Sources
SPACE PHYSICS	
PHYSICS AND CHEMISTRY LABORATORY	
4-P/C-1	Effect of the Space Environment on Chemical Reactions
4-P/C-2	Shape and Stability of Liquid-Vapor Interfaces
4-P/C-3	Boiling and Convective Heat Transfer in Zero-G

Table 4-1 (Page 5 of 8).

Cluster No.	Title
4-P/C-4	Effect of Zero-Gravity on the Production of Controlled Density Materials
4-P/C-5	Effect of Electric and Magnetic Fields on Materials
4-P/C-6	The Use of Zero-Gravity to Produce Materials Having Superior Physical Characteristics
4-P/C-7	Improvements of Materials by Levitation Melting
4-P/C-8	Effect of Zero-Gravity on the Production of Films and Foils
4-P/C-9	Effects of Zero-G on Liquid Releases, Size Distribution of Liquid Drops
4-P/C-10	Capillary Flow in Zero-G
4-P/C-11	Behavior of Superfluids in the Weightless State
PLASMA PHYSICS LABORATORY	
4-PP-1	Spacecraft Environment Interaction
4-PP-2	Energetic Particle Dynamics in the Magnetosphere (3 parts)
4-PP-2-1	Use of Alkali Metal Clouds as a Space Diagnostic
4-PP-2-2	Use of Electron Beams as a Space Diagnostic
4-PP-2-3	VLF Wave Propagation
4-PP-3	Thermal Plasma in the Ionosphere and Magnetosphere (3 parts)
4-PP-3-1	(Essentially the same as 4-PP-2-1)
4-PP-3-2	(Essentially the same as 4-PP-2-3)
4-PP-3-3	RF Plasma Resonance Studies
4-PP-4	Auroral Processes (3 parts)
4-PP-4-1	(Essentially the same as 4-PP-2-1)
4-PP-4-2	(Essentially the same as 4-PP-2-2)
4-PP-4-3	(Essentially the same as 4-PP-2-3)
COSMIC RAY LABORATORY	
4-CR-1	Charge and Energy Spectra of Cosmic Ray Nuclear Component
4-CR-2	Energy Spectrum of High-Energy Primary Electrons and Positrons
4-CR-3	Energy Spectrum and Spatial Distribution of Primary Gamma Rays
4-CR-4	Long-Lived Heavy Isotopes in Cosmic Rays
4-CR-5	Antinuclei in Cosmic Rays

Cluster No.	Title
4-CR-6	Quarks (Stable Fractionally Charged Particles) in Cosmic Rays
4-CR-7	Unknown Particles in Cosmic Rays
4-CR-8	Characteristics of Albedo Particles Above 100 MeV
4-CR-9	Nucleon-Nucleon Cross-Sections at High Energies
4-CR-10	Spallation Cross-Sections at High Energies
COMMUNICATIONS AND NAVIGATION	
NOISE	
5-N-1	Terrestrial Noise Measurements
5-N-2	Noise Source Identification
PROPAGATION	
5-P-1	Ionospheric Propagation Measurements
5-P-2	Tropospheric Propagation Measurements
5-P-3	Plasma Propagation Measurements
5-P-4	Multipath Measurements
TEST FACILITIES	
5-TF-1	Space Deployment and Calibration
5-TF-2	Demonstration and Test
COMMUNICATIONS SYSTEMS	
5-CS-1	MM Wave Demonstration
5-CS-2	Optical Frequency Demonstration
NAVIGATION SYSTEMS	
5-NS-1	Satellite Navigation Techniques for Terrestrial Users
5-NS-2	Laser Ranging
5-NS-3	Autonomous Navigation Systems for Space
5-NS-4	Surveillance Systems

Cluster No.	Title
5-NS-5	Collision Avoidance System Techniques
5-NS-6	Search and Rescue Systems

EARTH OBSERVATIONS

EARTH PHYSICS

6-EP-1	Photographic Coverage of the Earth
6-EP-2	Identification of Volcanic Activity

AGRICULTURE, FOREST, AND RANGE RESOURCES

6-A/F-1	Crop Inventory and Land Use
6-A/F-2	Soil Type Mapping
6-A/F-3	Crop Identification
6-A/F-4	Crop Vigor and Yield Prediction
6-A/F-5	Wildfire Detection and Mapping

GEOGRAPHY, CARTOGRAPHY, AND CULTURAL RESOURCES

6-G/C-1	Photographic and Multisensor Mapping

GEOLOGY

6-G-1	Rock and Soil Type Identification
6-G-2	Use of Earth's Crust to Store and Condition Commodities or Waste
6-G-3	Geologic Disaster Avoidance
6-G-4	Utilization of Geothermal Energy Sources
6-G-5	Mineral and Oil Deposit Discovery
6-G-6	Identification of Land Forms and Structural Forms

HYDROLOGY AND WATER RESOURCES

6-H-1	Determination of Pollution in Water Resources
6-H-2	Flood Warning and Damage Assessment
6-H-3	Synoptic Inventory of Major Lakes and Reservoirs

Table 4-1 (Page 8 of 8)

Cluster No.	Title
6-H-4	Synoptic Inventory of Snow and Ice
6-H-5	Survey of Soil Moisture in Selected Areas of the North American Continent
6-H-6	Location of Underground Water Sources in Selected Areas
6-H-7	Survey of Hydrologic Features of Major River Basins
OCEANOGRAPHY AND MARINE RESOURCES	
6-0-1	Ocean Pollution Identification, Measurement, and Effects
6-0-2	Solar Energy Partition and Heating in the Sea Surface Layer
6-0-3	Ocean Population Dynamics and Fishery Resources
6-0-4	Ocean Currents and Tide Forecasting
6-0-5	Ocean Physical Properties
6-0-6	Ocean Solid Boundary Processes
6-0-7	Ocean Surface Activity Forecasting
METEOROLOGY	
6-M-1	Determination of Boundary Layer Exchange Processes Using IR Radiometry
6-M-2	UHF Sferics Detection
6-M-3	Atmosphere Density Measurements by Stellar Occultation
6-M-4	Zero-G Environment Cloud Physics Experiment
6-M-5	Detection and Monitoring of Atmospheric Pollutants
6-M-6	Support of Studies of Special Geographical Areas

management interfaces, crew requirements, and logistic and resupply requirements are described.

4.1 ORBIT PARAMETERS

The experiment group descriptions were reviewed to collect the requirements that impact the selection of a space platform orbit. In certain cases, these requirements pose constraints on the range of acceptable orbit altitude and inclination. In the area of Earth Observations, the remote sensing requirements, allowable sun-target geometry, space platform-target geometry, and temporal and seasonal requirements represent further orbit selection factors. Manned Space Flight Capability, Space Biology and Space Physics investigations are essentially independent of orbital parameters notwithstanding radiation effects and logistical considerations. Space Astronomy observations, in certain cases involving faint sources, require synchronous altitudes when exposure times are considered. Communications and Navigation experiments, in certain cases involving ground site observations, are similar to the Earth Observation requirements. The discussion that follows will consider the requirements that are most important in the selection of orbital altitude and inclination parameters.

4.1.1 Orbit Inclination

Orbit inclination requirements are usually derived from a requirement to view a certain ground site, surface feature, area, or portion of the celestial sphere. Other factors that must be considered include the sensor look angles and angular field of view. A large number of truth sites and target locations are to be found in the Earth Observations experiment group descriptions. These targets can be segregated into two categories: (1) truth sites that are involved in a feasibility demonstration where the sensor signal must be correlated with ground and aircraft observations, and (2) sites that are to be observed when the sensor is in a data-gathering mode rather than an instrument-development mode. In some instances, the objectives of the research clusters can be achieved by completing the early research and feasibility demonstration activities. A matrix that identifies truth sites with research clusters is presented as Table 4-2. The sources of these data include both existing

Table 4-2 (page 1 of 3)

GROUND TRUTH SITES

Approximate Location		Name of Site	6-A/F-1	-2	-3	-4	-5	6-E/P-1	-2	6-G/C-1	6-G-1	-2	-3	-4	-5	-6	6-H-1	-2	-3	-4	-5	-6	-7	6-M-1	-2	-3	-4	-5	-6	6-O-1	-2	-3	-4	-5	-6	-7
14E	41N	Phlegraean Fields, Italy											X																							
14.5E	41N	Vesuvius, Italy											X																							
15E	37.5N	Etna, Sicily											X																							
29E	37.5N	Western Turkey Earthquake Zone											X																							
34.5E	28N	Coastal Plains west of Gulf of Agaba													X																					
36E	1N	Rift Valley, Suswa Area, Kenya							X					X																						
60.5E	26.5N	Southern Iran Earthquake Zone											X																							
106E	6S	Kratkatoa, Sumatra											X																							
107E	7S	Merapi, Indonesia											X																							
122E	8S	Genung, Ija											X																							
122E	14N	Taal, Philippines							X				X	X																						
131E	31N	Sakurajima, Japan											X																							
131E	33N	Aso, Japan											X																							
141E	38N	Braindaison, Japan											X																							
141E	42N	Toya, Japan											X																							
160.5E	55.9N	Bezymianny, Kamchatka											X																							
176E	39S	Ruapehu, New Zealand											X																							
168W to 36W	65S to 73N	North and South American Continents									X																									
162W	61N	North Cook Inlet, Alaska															X																			
157W	21N	Hawaii							X				X	X																						
157W	72N	Point Barrow, Alaska																																		
157W	72N	North Slope, Alaska							X					X	X																					
156W to 155W	19N to 20N	Island of Hawaii																					X													
154W	56N	Mt. Trident, Alaska											X																							
154W	57N	Mt Katmai, Alaska											X																							
145W	50N	Weather Ship Papa																													X		X	X		X
123.1W	38.7N	Geyserville, Calif.							X					X																						
122.5W	46.2N	Mt. St. Helena, Wash.	X		X	X	X		X					X																						
122W	37.5N	San Andreas Fault, Calif.											X																							

Table 4-2 (page 2 of 3)
GROUND TRUTH SITES

Approximate Location	Name of Site	6-A/F-1	-2	-3	-4	-5	6-E/P-1	-2	6-G/C-1	6-G -1	-2	-3	-4	-5	-6	6-H -1	-2	-3	-4	-5	-6	-7	6-M -1	-2	-3	-4	-5	-6	6-O -1	-2	-3	-4	-5	-6	-7
122W 38N	San Pable Reservoir, Calif.	X		X	X	X																													
121.8W 38.6N	Davis, Calif.	X	X	X	X															X															
121.8W 48.8N	Mt. Baker, Wash.	X		X	X	X																													
121.7W 45.5N	Mt. Hood, Oregon	X		X	X	X		X					X																						
121.7W 47N	Mt. Rainier, Wash.	X		X	X	X		X					X																						
121.5W 46.2N	Mt. Adams, Wash.	X		X	X	X		X				X	X																						
121.2W 40.5N	Mt. Lassen, Calif.							X				X	X																						
121.2W 48.2N	Cascade Glacier, Wash.																		X																
121W 40.1N	Bucks Lake, Calif.	X		X	X	X																													
120W 36N	Kettleman Hills, Calif.													X																					
119.2W to 118W 36N to 37.9N	Inyo National Forest, Calif.							X					X																						
119W 35.5N	San Joaquin Valley, Calif.													X																					
119W 37.8N	Mono Craters, Calif.							X				X	X																						
119W 38N	Mono Lake, Calif.																				X														
118.5W 37.7N	Benton, Calif.							X					X																						
118.5W 42.4N	Alvord Valley, Oregon	X		X	X	X																													
117.2W 32.9N	Scripps Beach, Calif.																												X	X	X	X	X	X	
117.2W 37.3N	Goldfield, Nevada													X																					
117W to 115W 33N to 34N	Southern California, Selected Sites						X		X																										
117W 36N	Coso Hot Springs, Calif.							X				X	X																						
116.9W 41.5N	Battle Mountain, Nevada													X																					
116.3W 34.7N	Pisgah Crater, Calif.							X					X																						
116.2W 43.6N	Boise, Idaho							X					X																						
116W 37.5N	AEC Nevada Test Site											X																							
115.9W 33N	Salton Sea, Calif.							X				X	X																						
112W 39.5N	Eureka, Utah													X																					
111.5W 32.8N	Silver Bell, Arizona													X																					
111.5W 44.5N	Yellowstone, Wyoming							X				X	X																						
110.1W 31.2N	Cananea, Mexico													X																					
107.7W 38N	Ouray-Silverton, Colorado													X																					

Table 4-2 (page 3 of 3)

GROUND TRUTH SITES

Approximate Location		Name of Site	6-A/F-1	-2	-3	-4	-5	6-E/P-1	-2	6-C/C-1	6-G-1	-2	-3	-4	-5	-6	6-H-1	-2	-3	-4	-5	-6	-7	6-M-1	-2	-3	-4	-5	-6	6-O-1	-2	-3	-4	-5	-6	-7
106.5W	32.7N	White Sands, New Mexico							X					X																						
106.4W	42.8N	Goose Egg Dome, Wyoming													X																					
100.9W	38N	Garden City, Kansas	X	X	X	X																														
98W	26N	Welasco, Texas	X	X	X	X															X															
95.8W	29.5N	Hawkins Salt Dome, Texas													X																					
95.6W	39N	Lawrence, Kansas	X	X	X	X																														
95.5W	29.5N	Galveston Beach, Texas																												X	X	X				
93W	47.5N	Mesabi Iron Range, Minn													X																					
91W	0	Isabela Island, Galapogos, Equador											X																							
87.1W	41.6N	Indiana Dunes, Indiana							X					X																						
86.8W	40.5N	Purdue Farms	X	X	X	X															X															
85W	10.5N	Mt. Arenal, Costa Rica											X																							
83.5W	9.3N	Volcanic Highlands, Costa Rica							X					X																						
82.5W to 81W	27N to 29N	West Coast, Florida															X																			
80.7W	28.4N	Cape Kennedy, Florida																							X											
80.3W	25.5N	Homestead, Florida	X	X	X	X																														
78.9W	33.8N	Myrtle Beach																																	X	
73W	41N	Connecticut River Estuary															X																			
70W	40N	Off Northeast Coast, U.S.																													X	X	X			X
66.5W	18.2N	Puerto Rico							X						X																					
64.7W	32.3N	Argus Island																													X		X	X		X
61W	62S	Deception Island												X																						
50W to 40W	24S	Coastal Plain - Sao Paulo to Rio Je Janeiro														X																				
21.5W	64.1N	Vasunlus-Eina, Iceland							X						X																					
19.5W	64N	Hekla, Iceland												X																						
17W	65.5N	Myvatn, Iceland							X					X	X																					
		TBD															X	X					X	X	X	X		X	X							
		N/A																									X									

instrumented field laboratories and projected requirements for new sites as defined by the principal investigators involved. Although these 84 sites do not encompass all the locations that would be necessary to accomplish all of the objectives of this discipline, the sampling is felt to be large enough to permit the drawing of conclusions about the latitude distribution of truth sites. The percent of truth sites visible from a low Earth orbit (100 to 30 nm) has been plotted as a function of orbit inclination in 5-deg increments and is presented in figure 4-1. Complete truth site coverage is achieved at inclinations between 75 and 105 degrees. Analysis of these data shows that, at an inclination of 55 degrees, 75 of the 84 truth sites (approximately 90 percent) would be visible from a low Earth orbit. The nine remaining sites are associated with the four research clusters listed below.

Research Cluster	No. of Truth Sites Specified	No. Not Visible at 55-Deg Inclination
6-E/P-2, 6-G-4	20	3
6-G-3	32	5
6-H-1	3	1

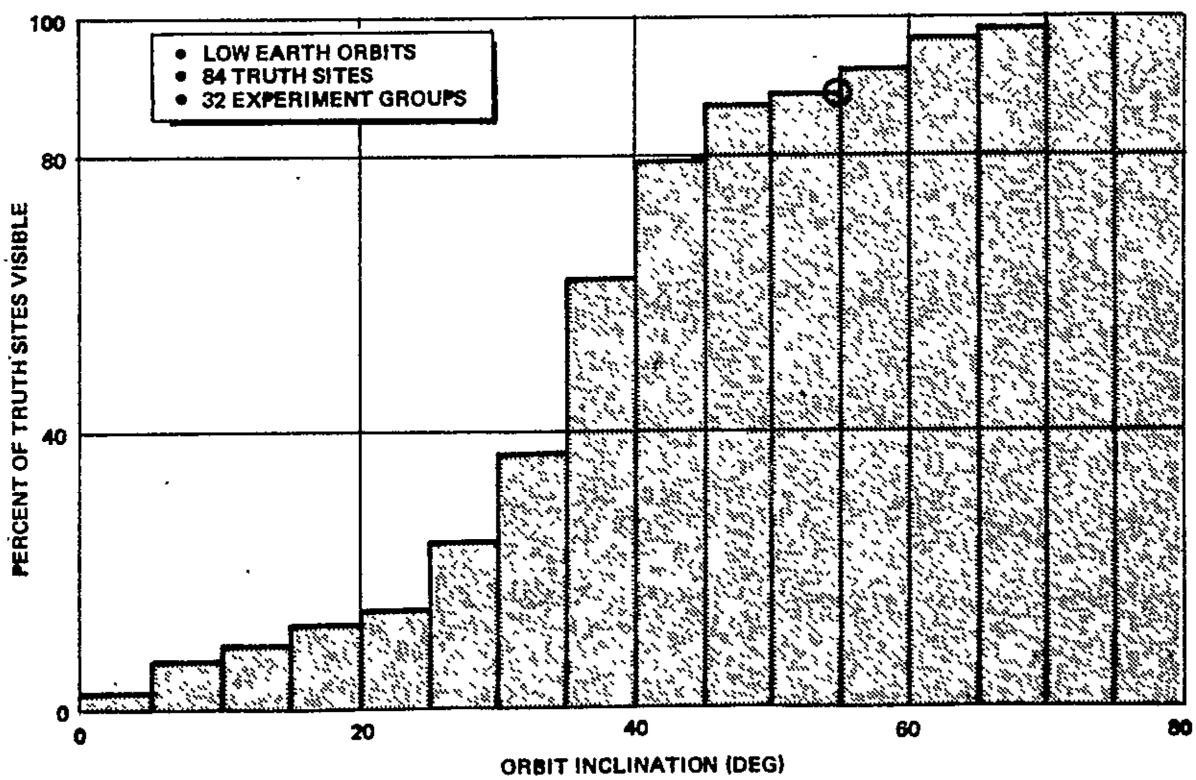

Figure 4-1. Earth Observations Truth Site Visibility from Orbit

The percentage of research clusters in Earth Observations that can be completely accommodated as a function of orbit inclination is presented in Figure 4-2. These data show that 50 percent of the research clusters require an inclination of at least 70 deg. These operational requirements have been interpreted as desirable, rather than mandatory, features of the orbit. This interpretation is reinforced by the research cluster where, for example, areas with latitudes of 60 to 70 deg are desired, and latitudes of 55 deg are acceptable.

On the basis of the preceding discussion, the orbit inclination requirements were listed for the clusters to which they pertained. These data (Table 4-3) have classified the clusters as to whether an orbit with low (30-deg), medium (30- to 55-deg), or high (55-deg) inclination is required.

4.1.2 Orbit Altitude

Altitude requirements have been extracted from each of the research clusters and separated into two classifications: (1) experiments that must be performed in orbit at synchronous altitude or higher, and (2) experiments that require low Earth orbits. These data are listed in Table 4-4.

The altitude requirements for Earth Observations experiments specifying acceptable altitude ranges for low Earth orbits (100 to 30 nm) are summarized in Figure 4-3, where the percentage of requirements satisfied has been plotted as a function of orbit altitude in 50-nmi increments. The orbit altitudes that fulfill most of the requirements lie in the 200- to 250-nmi range.

As a first approximation to the orbit eccentricity requirement, circular orbits were considered. This assumption was made for many of the research clusters, such as Earth-viewing experiments with fixed-focal-length cameras. When eccentric orbits are encountered, the altitude history must be known to allow the imagery to be scaled appropriatley. Other considerations such as precession of the line of apsides and increased orbit-keeping propellant requirements favor circular orbits.

Until a specific experiment program is synthesized, only a preliminary altitude selection can be made. By examining spacecraft operational considerations

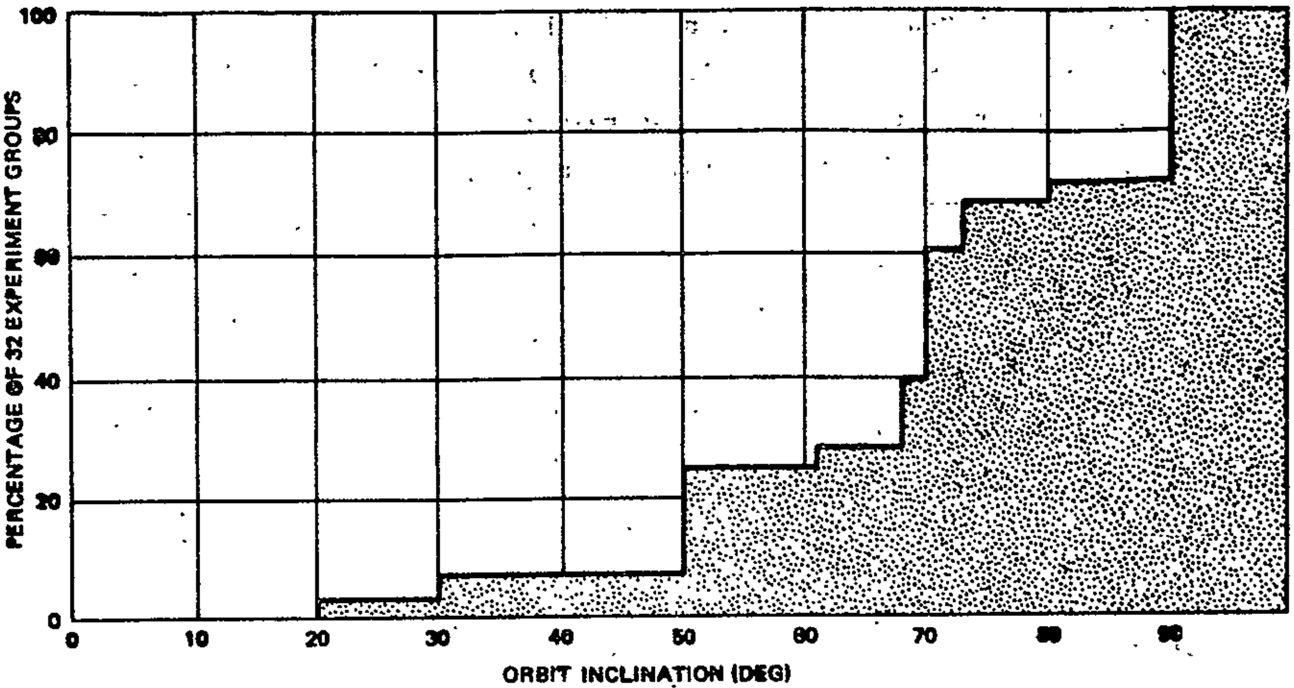

Figure 4-2. Summary of Inclination Requirements (Operational Mode)—Low Earth Orbit.

Table 4-3

INCLINATION REQUIREMENTS

Low (<30°)	Medium (30°<i<55°)					High (>55°)
4-PP-2	5-N-2	6-A/F-3	6-H-7	6-G-3	6-O-6	5-N-1
5-P-2	5-NS-4	6-A/F-4	6-M-1	6-G-4	6-O-7	6-H-4
	5-NS-5	6-A/F-5	6-M-2	6-G-5	6-EP-1	
	5-NS-6	6-H-1	6-M-3	6-O-1	6-EP-2	
	5-P-1	6-H-2	6-M-5	6-O-2	6-G/C-1	
	5-P-3	6-H-3	6-M-6	6-O-3		
	6-A/F-1	6-H-5	6-G-1	6-O-4		
	6-A/F-2	6-H-6	6-G-2	6-O-5		

NOTE: Inclination requirements are associated with these research clusters. The remaining clusters have no specific inclination requirements, or they are yet to be identified.

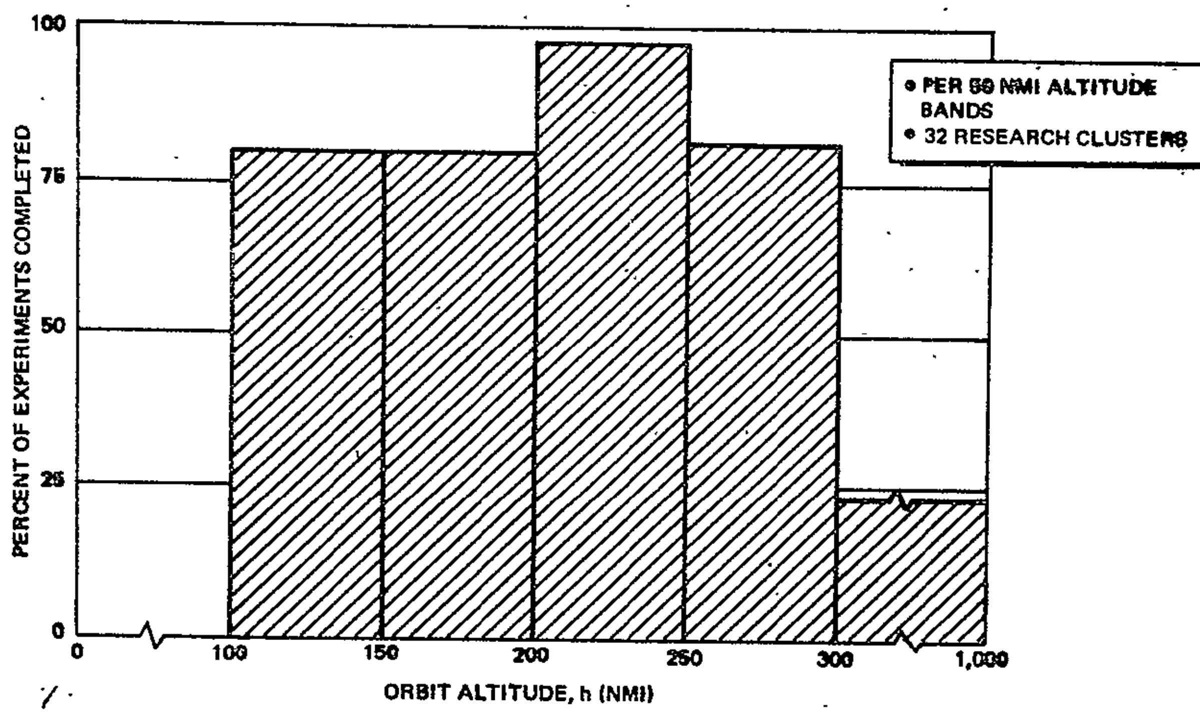

Figure 4-3. Summary of Altitude Requirements–Low Earth Orbit

Table 4-4

ALTITUDE REQUIREMENTS

Synchronous or Higher	Low Earth Orbit	
4-PP-2	1-EE-2	6-A/F-1, through -5
3-LF	1-EE-4-1	6-H-1, through -7
1-EE-4-2*	1-EE-4-3	6-M-1, through -3
5-P-2	3-OS	6-M-5 and 6-M-6
	3-XR	6-G/C-1
TOTAL: 4	5-N-1	6-G-1, through -5
	5-N-2	6-O-1, through -7
While not a mandatory requirement 3-OB and 3-OW would prefer these altitudes.	5-P-1	6-EP-1
	5-P-3	6-EP-2
	5-P-4	
	5-NS-1	
	5-NS-3	
	5-NS-4	

NOTE: Altitude requirements are associated with these research clusters. The remaining clusters have no altitude requirements, or they are yet to be identified.

*Translunar or interplanetary

(radiation hazards, ground station coverage, rendezvous compatibility, and payload capability) for a given experiment program, a specific altitude or altitude history can be chosen, using the experiment program as the basis for the selection criteria (such as ranking of experiments and maximum percentage of each accomplished). Altitude affects not only resolution and ground swath width but also, in consort with inclination, the coverage repetition. The experiment parameters that must be considered in altitude selection, then, are resolution, swatch width, and ground track repeatability.

For experiments having conflicting requirements, it may be possible to change spacecraft altitude and satisfy each set of experiment requirements individually provided they can be performed non-concurrently.

4.2 SPACECRAFT SUBSYSTEM INTERFACE IMPLICATIONS

Each research cluster description was examined for any requirements that have a major impact on the resources of the host spacecraft. These interface requirements are presented in summary in Table 4-5. For each research cluster, 12 of the more important items were examined, and tabulated as follows:

1. Average electrical power demand, stated in watts.
2. Peak electrical power demand, stated in watts.
3. Logistics requirements that demand special handling or procedures.
4. Environmental requirements for controlled atmospheric conditions.
5. Thermal control requirements for cooling (or heating).
6. Spacecraft pointing requirements, stated in terms of orientation limits in degrees.
7. Spacecraft stability limits in terms of residual body rates in deg/sec.
8. Onboard acceleration and artificial gravity requirements in number of g.
9. Orbital altitude requirements in nautical miles.
10. Orbital inclinations requirements (beta angle) in degrees.
11. Viewing requirements for specific geometrical relationships of the sun, target, and spacecraft, stated in degrees.
12. Requirements for repeated temporal coverage of the same geographic location (Q-factor) stated in number of events per day.

Table 4-5 (Page 1 of 9)

SPACE RESEARCH FACILITY INTERFACE SUMMARY

LEGEND:

NR No Specific Requirement
N/A Item Not Applicable
TBD To Be Determined after Additional Analysis
UNK Relationship Unknown

Research Cluster		Electrical		Logistics	Environment		Stabilization		Acceleration	Orbit Parameters		Viewing Restrictions	
Cluster No.	Short Title	(1) Average (watts)	(2) Peak (watts)	(3) Special Handling	(4) Atmosphere (gases)	(5) Cooling (watts)	(6) Pointing (degrees)	(7) Rate (degree/sec)	(8) Level (g's)	(9) H (nmi)	(10) i (degrees)	(11) B* (degrees)	(12) Q (events/day)
1-BM-4	Cardiovascular	100	1,000	Film	Air	100 to 1,000 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BM-5	Medical Problems	240	1,200	NR	Air	1,200 + UNK	NR	NR	NR	NR	NR	N/A	N/A
1-BM-6	Stress Response	350$^{(1)}$	870$^{(1)}$	NR	Air	350 to 870 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BM-7	Nervous System	1	1	Film	Air	Metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BM-8	Gastrointestinal	40	45	NR	Air	40 to 45 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BM-10	Blood and Urine	200	300	NR	Air	200 to 300 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BM-12	Instrumented Animals	100	100	NR	Air	100 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BM-13	Pulmonary Function	50	55	NR	Air	50 to 55 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BM-14	Metabolism	20	27	NR	Air	20 to 27 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BM-15	Centrifuge Studies	280	5,300$^{(2)}$	NR	Air	280 + metabolic	NR	NR	Ambient to 1.$^{(2)}$	NR	NR	N/A	N/A
1-BR-1	Sensory Behavior$^{(4)}$	180	400	NR	Air	180 to 400 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BR-2	Group Dynamics	50	100	NR	Air	50 to 100 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BR-3	Complex Tasks	47	187	NR	Air	2,187 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-BR-4	Skill Retention	200	5,300$^{(2)}$	NR	Air	200 to 5,300 + metabolic	NR	NR	Ambient to 1.$^{(2)}$	NR	NR	N/A	N/A
1-BR-6	Performance Tests	50	100	NR	Air	50 to 100 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-MM-1	Controls and Displays$^{(3)}$	50	1,000	NR	Air	50 to 1,000 + metabolic	NR	NR	Ambient	NR	NR	UNK	UNK
1-MM-2	Locomotion	40	50	NR	N/A	50	0.25	0.003	Ambient	NR	NR	N/A	N/A
1-MM-3	Habitability	40	50	Film	Air	40 to 50 + metabolic	NR	NR	Ambient	NR	NR	N/A	N/A
1-MM-4	Activity Cycles	100	150	NR	Air	2,150	NR	NR	Ambient	NR	NR	N/A	N/A
1-MM-5	Performance AIDS	345	425	NR	Air	Metabolic	NR	NR	Ambient	NR	NR	N/A	N/A

Table 4-5 (Page 2 of 9)

SPACE RESEARCH FACILITY INTERFACE SUMMARY

Research Cluster		Electrical		Logistics	Environment		Stabilization		Acceleration	Orbit Parameters		Viewing Restrictions	
Cluster No.	Short Title	(1) Average (watts)	(2) Peak (watts)	(3) Special Handling	(4) Atmosphere (gases)	(5) Cooling (watts)	(6) Pointing (degrees)	(7) Rate (degree/sec)	(8) Level (g's)	(9) H (nmi)	(10) i (degrees)	(11) β^* (degrees)	(12) Q (events/day)
1-LS-1	Phase Change	200	1,500	NR	Air	1,500	0.25	0.003	10^{-6}[5]	NR	NR	N/A	N/A
1-LS-2	Material Transport	800	1,500	NR	Air	1,500	0.25	0.003	10^{-6}[6]	NR	NR	N/A	N/A
1-LS-3	Atmosphere Supply	1,000	1,200	NR	Air	1,000	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-4	Water Management	100	250	NR	NR	200	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-5	Water Electrolysis	630	700	NR	Air	200	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-6	Food Management	3000	6000	NR	Air	700	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-7	Atmosphere Purification	300	400	NR	Air	400	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-8	Life Support Monitoring	TBD[8]	TBD[8]	NR	Air	TBD[8]	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-9	Waste Management	500	900	NR	Air	400	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-10	Heat Transport	1000	1,200	NR	NR	800	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-11	Crew Systems	TBD[8]	TBD[8]	NR	Air	TBD[8]	NR	NR	Ambient	NR	NR	N/A	N/A
1-LS-12	Maintenance and Repair	TBD[8]	TBD[8]	NR	Air	TBD[8]	NR	NR	Ambient	NR	NR	N/A	N/A
1-EE-1	Data Management	100	250	Film	NR	250	NR	NR	Ambient	NR	NR	UNK	UNK
1-EE-2	Structures	550	1,000	NR	NR	NR	0.25	0.003	Ambient	100 to 250	70	N/A	N/A
1-EE-3	Stability and Control	530	765	NR	NR	100	0.1	0.003	Ambient[7]	NR	NR	UNK	UNK
1-EE-4	Navigation and Guidance	100	TBD	NR	Cryo	100	0.25	0.003	NR	NR	NR	TBD	TBD
1-EE-5	Communications	50	50	NR	NR	50	0.25	0.003	NR	NR	NR	TBD	TBD
1-OE-1	Logistics and Resupply	400	400	NR	Air	400	0.25	0.003	Ambient	NR	NR	N/A	N/A
1-OE-2	Maintenance and Repair	200	200	Film	NR	200	0.25	0.003	Ambient	TBD[9]	TBD[9]	N/A	N/A
1-OE-3	Assembly and Deployment	TBD	TBD	NR	Air	NR	0.25	0.003	Ambient	NR	NR	N/A	N/A
1-OE-4	Module Operations	TBD	TBD	NR	Air	NR	0.25	0.003	Ambient	NR	NR	N/A	N/A
1-OE-5	Vehicle Support	NIL	NIL	NR	Air	NR	0.25	0.003	Ambient	NR	NR	UNK	UNK

Table 4-5 (Page 3 of 9)
SPACE RESEARCH FACILITY INTERFACE SUMMARY

Research Cluster		Electrical		Logistics	Environment		Stabilization		Acceleration	Orbit Parameters		Viewing Restrictions	
Cluster No	Short Title	(1) Average (watts)	(2) Peak (watts)	(3) Special Handling	(4) Atmosphere (gases)	(5) Cooling (watts)	(6) Pointing (degrees)	(7) Rate (degree/sec)	(8) Level (g's)	(9) H (nmi)	(10) i (degrees)	(11) B∢ (degrees)	(12) Q (events/day)
2-VB-1	Preliminary Vertebrates	450	2,200	Film	Air and Steam	Metabolic	NR	NR	10^{-5} (10)(11)	NR	NR	N/A	N/A
2-VB-2	Intermediate Vertebrates	450	2,200	Film	Air	Metabolic	NR	NR	10^{-5} (10)(11)	NR	NR	N/A	N/A
2-VB-3	Advanced Vertebrates	450	2,220	Film	Air	Metabolic	NR	NR	10^{-5} (10)(11)	NR	NR	N/A	N/A
2-IN-1	Preliminary Invertebrates	80	80	Film	Air	Metabolic	NR	NR	10^{-4}	NR	NR	N/A	N/A
2-IN-1	Intermediate Invertebrates	80	80	Film	Air	Metabolic	NR	NR	10^{-4}	NR	NR	N/A	N/A
2-IN-3	Advanced Invertebrates	80	80	Film	Air	Metabolic	NR	NR	10^{-4}	NR	NR	N/A	N/A
2-P/T-1	Preliminary Protists	440	2,400	Film	Air	Metabolic	NR	NR	10^{-4}	NR	NR	N/A	N/A
2-P/T-2	Intermediate Protists	480	2,440	Film	Air	Metabolic	NR	NR	10^{-4}	NR	NR	N/A	N/A
2-P/T-3	Advanced Protists	590	2,550	Film	Air	Metabolic	NR	NR	10^{-3}	NR	NR	N/A	N/A
2-PL-1	Preliminary Plants	265	915	Film	Air	Metabolic	NR	NR	10^{-5} (10)(11)	NR	NR	N/A	N/A
2-PL-2	Intermediate Plants	265	915	Film	Air	Metabolic	NR	NR	10^{-5} (10)(11)	NR	NR	N/A	N/A
2-PL-3	Advanced Plants	265	915	Film	Air	Metabolic	NR	NR	10^{-5} (10)(11)	NR	NR	N/A	N/A

Table 4-5 (Page 4 of 9)

SPACE RESEARCH FACILITY INTERFACE SUMMARY

Research Cluster		Electrical		Logistics	Environment		Stabilization		Acceleration	Orbit Parameters		Viewing Restrictions	
Cluster No.	Short Title	(1) Average (watts)	(2) Peak (watts)	(3) Special Handling	(4) Atmosphere (gases)	(5) Cooling (watts)	(6) Pointing (degrees)	(7) Rate (degree/sec)	(8) Level (g's)	(9) H (nmi)	(10) i (degrees)	(11) β_s (degrees)	(12) Q (events/day)
3-OW	Optical Structure	930	960	Film	Cryo	TBD	6×10^{-6}	1.4×10^{-6}	NR(12)	SYNC	NR	NR(14)	NR
3-XR	X-ray Sources	406	960	TBD	NR	773	7×10^{-5}	7×10^{-6}	NR(12)	100 to 400	NR	NR	NR
3-LF	Low Frequency Radio	366	400	NR	NR	400	TBD(13)	TBD(13)	NR(12)	SYNC	NR	NR	NR
3-OB	Optical Planetary	1,100	1,920	Film	Cryo	TBD	7×10^{-4}	7×10^{-6}	NR(12)	SYNC	NR	NR(14)	NR
3-OS	Optical Surveys	170	960	Film	Cryo	TBD	3×10^{-4}	3×10^{-6}	NR(12)	100 to 400	NR	NR(14)	NR
3-SO	Solar Optical	TBD	TBD	Film	Cryo	TBD	3×10^{-4}	3×10^{-6}	NR(12)	Low	SUN SYNC	None	None
3-OP	Stellar Photometry	170	960	TBD	NR	TBD	3×10^{-4}	3×10^{-6}	NR(12)	100 to 400	NR	NR(14)	NR(14)

Table 4-5 (Page 5 of 9)

SPACE RESEARCH FACILITY INTERFACE SUMMARY

Research Cluster		Electrical		Logistics	Environment		Stabilization		Acceleration	Orbit Parameters		Viewing Restrictions	
Cluster No.	Short Title	(1) Average (watts)	(2) Peak (watts)	(3) Special Handling	(4) Atmosphere (gases)	(5) Cooling (watts)	(6) Pointing (degrees)	(7) Rate (degree/sec)	(8) Level (g's)	(9) H (nmi)	(10) i (degrees)	(11) β* (degrees)	(12) Q (events/day)
4-P/C-1	Chemical Reactions	750	1,000	Film	TBD	TBD	0.25	0.003	10^{-3}	N/A	N/A	N/A	N/A
4-P/C-2	Liquid-Vapor Interface	400	500	Film	TBD	1,500	0.1	0.003	10^{-5}, 10^{-6}(15)	N/A	N/A	N/A	N/A
4-P/C-3	Heat Transfer in Zero-G	30	3,000	Film	Inert or Noble gas	3,300	0.1	0.003	10^{-2} to 10^{-5}(17)	N/A	N/A	N/A	N/A
4-P/C-4	Controlled Density	5,000	20,000	Film	Various(16)	TBD	0.1	0.003	10^{-3} to 10^{-4}(17)	N/A	N/A	N/A	N/A
4-P/C-5	E and M Fields	200	2,000	Film	TBD*	2,000	0.1	0.003	10^{-3}	NR	NR	N/A	N/A
4-P/C-6	Super Materials	5,000	20,000 (20)	Film	TBD	TBD (20,000)	0.25	0.003	10^{-2} to 10^{-5}(17)				
4-P/C-7	Levitation Melting	2,000	5,000	Film	TBD	TBD (5,000)	0.25	0.003	10^{-3}	NE	NR	N/A	N/A
4-P/C-8	Films and Foils	5,000	20,000 (20)	Film	TBD	TBD (20,000)	0.25	0.003	10^{-3}	NR	NR	N/A	N/A
4-P/C-9	Liquid Releases	175	200	Film	Air or He	Nominal	0.25	0.003	10^{-3}	NR	NR	N/A	N/A
4-P/C-10	Capillary Flow	250	400	Film	Inert $+O_2$	400	0.25	0.003	10^{-2}, 10^{-4} 10^{-6}(17)	NR	NR	N/A	N/A
4-P/C-11	Superfluids	20	20	Film	NR	Nominal	0.25	0.003	10^{-2}, 10^{-4}, 10^{-6}(17)	NR	NR	N/A	N/A
4-CR-1	Nuclear Component	10,000 (18)(20)(4)	10,000 (18)(20)	Film (19)	Air and LH_2	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-CR-2	Primary e^- and e^+	10,000 (18)(20)	10,000 (18)(20)	Film (19)	Air and LH_2	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-CR-3	Primary Gamma Rays	10,000 (18)(20)	10,000 (18)(20)	Film (19)	Air and LH_2	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-CR-4	Heavy Isotopes	10,000 (18)(20)	10,000 (18)(20)	Film (19)	Air and LH_2	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-CR-5	Antinuclei	10,000 (18)(20)	10,000 (18)(20)	Film (19)	Air and LH_2	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-CR-6	Quarks	10,000 (18)(20)	10,000 (18)(20)	Film (19)	Air and LH_2	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-CR-7	Unknown Particles	10,000 (18)(20)	10,000 (18)(20)	Film (19)	Air and LH_2	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-CR-8	Albedo Particles	10,000 (18)(20)	10,000 (18)(20)	Film (19)	Air and LH_2	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-CR-9	Differential p-p	10,000 (18)(20)	10,000 (18)(20)	Film (19)	Air and LH_2	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-CR-10	Differential Spallation	10,000 (18)(20)	10,000 (18)(20)	Film (19)	Air and LH_2	See (18)	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-PP-1	SS Environment Interaction	TBD	TBD	TBD	TBD	TBD	0.25	0.003	NR	TBD	TBD	UNK	UNK
4-PP-2, -4	Particle Dynamics, Auroral Processes	100	1,000	NR	NR	Nominal	0.25	0.003	NR	12,400	>55	UNK	UNK
4-PP-3	Thermal Plasma	TBD	TBD	NR	NR	Nominal	0.25	0.003	NR	TBD	TBD	UNK	UNK

Table 4-5 (Page 6 of 9)

SPACE RESEARCH FACILITY INTERFACE SUMMARY

Research Cluster		Electrical		Logistics	Environment		Stabilization		Acceleration	Orbit Parameters		Viewing Restrictions	
Cluster No	Short Title	(1) Average (watts)	(2) Peak (watts)	(3) Special Handling	(4) Atmosphere (gases)	(5) Cooling (watts)	(6) Pointing (degrees)	(7) Rate (degree/sec)	(8) Level (g's)	(9) H (nmi)	(10) i (degrees)	(11) β (degrees)	(12) Q (events/day)
5-N-1	Terrestrial Noise	25	25	NR	NR (21)	Nominal	1.0	0.05	NR	200 to 1,000	90	NR	TBD
5-N-2	Noise Identification	25	25	Film	NR (21)	Nominal	0.25	0.003	NR	TBD	55	NR	TBD
5-P-1	Ionosphere Propagation	25	25	NR	NR (21)	Nominal	0.25	0.003	NR	100 to 200	90	N/A	TBD
5-P-2	Troposphere Propagation	25	25	NR	NR (21)	Nominal	0.1	0.003	NR	SYNC	0	N/A	N/A
5-P-3	Plasma Propagation	25	25	NR	NR (21)	Nominal	NR	NR	NR	100 to 200 (22)	40	N/A	N/A
5-P-4	Multipath Measurements	50	50	NR	NR (21)	Nominal	NR	NR	NR	100 to 1,000	NR	N/A	TBD
5-TF-1	Laboratory Deployment	800	2,000	Film	NR (21)	2,000	NR	NR	NR	100 to SYNC	NR	NR	TBD
5-TF-2	Demonstration and Test	800	2,000	Film	NR (21)	2,000	NR	NR	NR	100 to SYNC	NR	NR	TBD
5-CS-1	MM Wave Demonstration	350	400	NR	NR (21)	400	0.5	0.05	NR	NR	NR	NR	TBD
5-CS-2	Optical Demonstration	500	1,500	Film	NR (21)	1,500	0.5	0.05	NR	200 to 1,000	TBD	NR	TBD
5-NS-1	Navigation Techniques	50	100	NR	NR (21)	100	0.25	0.003	NR	100 to SYNC (23)	55	NR	TBD
5-NS-2	Laser Ranging	500	1,500	Film	NR (21)	1,500	0.25	0.003	NR	TBD	TBD	NR	TBD
5-NS-3	Autonomous Navigation	50	100	NR	NR (21)	Nominal	0.25	0.003	NR	100 to SYNC	NR	NR	TBD
5-NS-4	Surveillance Systems	25	50	NR	NR (21)	Nominal	0.25	0.003	NR	TBD	TBD	NR	TBD
5-NS-5	Collision Avoidance	25	50	NR	NR (21)	Nominal	0.25	0.003	NR	TBD	TBD	NR	TBD
5-NS-6	Search and Rescue	50	100	NR	NR (21)	Nominal	0.25	0.003	NR	TBD	TBD	NR	TBD

SPACE RESEARCH FACILITY INTERFACE SUMMARY

Research Cluster		Electrical		Logistics	Environment		Stabilization		Acceleration	Orbit Parameters		Viewing Restrictions	
Cluster No.	Short Title	(1) Average (watts)	(2) Peak (watts)	(3) Special Handling	(4) Atmosphere (gases)	(5) Cooling (watts)	(6) Pointing (degrees)	(7) Rate (degree/sec)	(8) Level (g's)	(9) H (nmi)	(10) i (degrees)	(11) β* (degrees)	(12) Q (events/day)
6-EP-1	Photographic Coverage	1,300	2,100	Film (24)	NR	NR	0.5	0.03	NR	100 to 300	30 to 90	30 to 90	1
6-EP-2	Volcanic Activity	4,000	4,700	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	55	30	1/100
6-A/F-1	Crop Inventory	4,800	5,600	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	220 to 270	45 to 60	30 to 90	1/8 and 1/30
6-A/F-2	Soil Type Mapping	4,600	5,400	Film (24)	Cryo	TBD (25)	0.5	0.03 (26)	NR	220 to 270	45 to 60	60 to 90	1/8 and 1/30
6-A/F-3	Crop Identification	4,600	5,500	Film (24)	Cryo	TBD (25)	0.5	0.03 (26)	NR	220 to 270	45 to 60	60 to 90	1/8
6-A/F-4	Crop Vigor and Yield	4,600	5,400	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	220 to 270	45 to 60	60 to 90	1 or 1/8
6-A/F-5	Wildfire Detection	2,200	3,000	Film (24)	Cryo	TBD (25)	0.5	0.03 (26)	NR	220 to 270	45 to 60	30 to 90	1 and 2
6-G/C-1	Multisensor Mapping	1,300	2,100	Film (24)	NR	NR	0.5	0.03	NR	100 to 300	30 to 90	30 to 90	1
6-G-1	Rocks and Soils	3,900	4,600	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	73 to 107	30 to 90	1/10
6-G-2	Use of Earth's Crust	3,900	4,600	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	55	30	1/10
6-G-3	Geologic Disasters	3,300	3,700	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	55	25 to 90	1 and 1/30
6-G-4	Geothermal Sources	4,000	4,700	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	55	30	1/100
6-G-5	Minerals and Oils	3,900	4,600	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	55	15, 30, 60	1/100
6-G-6	Land Forms	3,900	4,600	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	73 to 107	30 to 90	1/10
6-H-1	Water Pollution	1,300	2,000	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	55	30 to 90	1
6-H-2	Flood Warning	3,200	3,500	Film (24)	Cryo	TBD (25)	0.5	0.03 (26)	NR	125 to 275	55	30 to 90	1 and 1/8
6-H-3	Synoptic Lake Inventory	3,800	4,600	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	55	30 to 90	1/90
6-H-4	Synoptic Ice Inventory	3,200	3,500	Film (24)	Cryo	TBD (25)	0.5	0.03 (3)	NR	125 to 275	55	30 to 90	1/90
6-H-5	Soil Moisture	700	1,000	Film (24)	Cryo	TBD (25)	0.5	0.03 (3)	NR	125 to 275	90	30 to 90	1/8
6-H-6	Underground Sources	600	1,000	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 275	50	<0 and >30	1/180
6-H-7	Major River Basins	3,800	4,600	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	125 to 175	55 to 68	<30 and 0 to 90	1/90
6-M-1	Boundary Layer Exchange	600	900	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	100 to 300	30 to 70	NR	NR
6-M-2	UHF Sferics Detection	500	800	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	100 to 400	30 to 55	NR	NR
6-M-3	Atmospheric Density	65	100	Film (24)	NR	Nominal	0.02 (27)	0.05	NR	100 to 300	0 to 50	NR	NR
6-M-4	Zero-G Cloud Physics	200	200	Film (24)	N_2, O_2, CO_2, H_2O	Nominal	NR	NR	10^{-5}	N/A	N/A	N/A	N/A
6-M-5	Atmospheric Pollutants	500	800	Film (24)	Cryo	TBD (25)	0.5	0.05	NR	200 to 300	30 to 55	30 to 90	NR
6-M-6	Special Area Studies	600	1,000	Film (24)	Cryo	TBD (25)	0.5	0.05	NR	100 to 300	20 to 30	TBD	TBD
6-O-1	Ocean Pollution	700	1,000	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	100 to 250	55	30 to 60	1
6-O-2	Solar Energy Partition	800	1,100	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	100 to 250	55	30 to 60	1
6-O-3	Ocean Population Dynamics	700	1,000	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	100 to 250	55	30 to 60	1

Table 4-5 (Page 8 of 9)

SPACE RESEARCH FACILITY INTERFACE SUMMARY

Research Cluster		Electrical		Logistics	Environment		Stabilization		Acceleration	Orbit Parameters		Viewing Restrictions	
Cluster No.	Short Title	(1) Average (watts)	(2) Peak (watts)	(3) Special Handling	(4) Atmosphere (gases)	(5) Cooling (watts)	(6) Pointing (degrees)	(7) Rate (degree/sec)	(8) Level (g's)	(9) H (nmi)	(10) i (degrees)	(11) β^* (degrees)	(12) Q (events/day)
6-O-4	Currents and Tides	3,100	3,300	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	100 to 250	55	NR	1
6-O-5	Physical Properties	3,000	3,300	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	100 to 200	55	NR	1
6-O-6	Ocean Solid Boundary	1,500	2,200	Film (24)	Cryo	TBD (25)	0.5	0.03	NR	100 to 250	55	NR	1
6-O-7	Surface Activity	700	900	Film (24)	Cryo	TBD (25)	0.5	0.03 (28)	NR	100 to 250	55	NR	1

Table 4-5 (Page 9 of 9)

SPACE RESEARCH FACILITY INTERFACE SUMMARY

REMARKS:

(1) Power levels required for thermal enclosure; when not used power levels reduce to 40 to 45 watts.

(2) Onboard manned centrifuge required. High starting and runup power requirement may require secondary batteries. Stabilization and control disturbance need to be noted.

(3) Research may be accommodated by coordination of design of onboard stabilization and control subsystem.

(4) Recommends Space Station rotation and/or centrifuge.

(5) Investigations require this acceleration level for periods of 1 hour.

(6) Investigations require this acceleration level for periods of 5 hours.

(7) Some of the functions performed by onboard investigators and members of the crew produce significant disturbances. The effect of these disturbances on the spacecraft could be measured to obtain important data concerning disturbance torques and accelerations.

(8) Research data may be derived from other experiments; unique requirements need to be determined when experiment groupings are resolved.

(9) Orbit must be selected so as to be safe for EVA.

(10) Some investigators may settle for 10^{-4} g.

(11) Some experiments require onboard centrifuge.

(12) The optical instruments need to be isolated from vibration and torque disturbances produced in the spacecraft.

(13) Scanning required at a 6-degree/second rate.

(14) Protection required to prevent instruments from inadvertently pointing toward the sun.

(15) Level required for periods of 2 hours.

(16) Gases required include N_2, O_2, He, A, and others.

(17) May require onboard centrifuge or Space Station rotation.

(18) Power levels required for cooling superconducting magnet by closed system. For passive resupply of cryogen total power would be about 3,000 watts.

(19) Periodic major reconfiguration of experimental apparatus may be required at 1- to 3-month intervals.

(20) Depending on duty cycle, high-power level demands may require secondary batteries.

(21) No specific atmosphere requirements except for no corrosive components.

(22) Orientation of sensors are critical during reentry in order to make measurements of spacecraft perturbations of plasma.

(23) Surface and airborne targets required to 100,000-foot altitude.

(24) Retrieval and resupply of photographic material considerations may result in onboard processing requirements.

(25) Amount of cooling for IR detectors depends on details of open or closed loop refrigeration installation.

(26) Spacecraft roll maneuvers required to calibrate microwave radiometer.

(27) For target acquisition 1 min, for target tracking 2 sec.

(28) Spacecraft yaw maneuvers required to calibrate radar altimeter/scatterometer.

It was not possible to assign a quantitative factor to describe the experimental interface requirements in every case itemized in Table 4-5. In some cases, the specific item was not of major importance to the research, and these cases were noted as being No Specific Requirements (NR). In other cases, an item was not applicable as shown by Not Applicable (N/A) in Table 4-5. When it was found that additional analysis, conceptual design, or a trade study would be required to establish a meaningful quantitative description of the interface requirements, the entry To Be Determined (TBD) was used. In a few cases, the knowledge on hand was insufficient to identify the requirements, as noted in the table by Unknown (UNK). The following paragraphs address some of the more pertinent demands of the research clusters on the mission and spacecraft interface.

4.2.1 Electrical Power Subsystem

From the data contained in Table 4-5, each of the research clusters has been reviewed for average and peak power demands. The six research categories are discussed in the following paragraphs in terms of the unusual power demands for their respective experimentation areas. The estimates of average power demands are also presented in the summary of weight, volume, and power in Table 4-12, which follows later in this section.

Most of the Manned Space Flight Capability experiment electrical-power requirements were estimated to fall below an average of 500 w, with most averages being less than 200 w. The peak power demands are generally below 1 kw and of short duration. Research Clusters 1-BM-15 and 1-BR-4 include a manned onboard centrifuge as part of the experimental apparatus.

The centrifuge requires a high-torque starting power of about 5.3 kw for about 1 min, compared with an operating power of about 200 w.

The Space Biology experiment electrical power requirements are moderate, varying on the average between 80 and 600 w. Peak power may be as high as 2.5 kw for the research clusters that require large apparatus, such as an onboard centrifuge.

The three Space Astronomy optical-region research clusters use common equipment and therefore have similar power requirements and are less than 1 kw. The remaining two research clusters require less electrical power.

The Space Physics research clusters demand average power levels from about 50 w to 10 kw, with peaks from 200 w to 20 kw. The 20-kw peaks (clusters 4-P/C-4, -6, and -8) will require special power-source provisions, such as batteries. These three research clusters, involving exotic material investigations, require short periods of relatively high power levels in order to process (at high temperature and high pressure) controlled-density metals, films, and foils, and materials with superior characteristics. Other peaks of up to 5 kw for 18 min to 1-hr duration may limit other experiment operations during the peak time periods (4-P/C-3 and 4-P/C-7). These two research clusters involve thermal processes, including heat transfer and levitation-melting investigations. One group of research clusters requires 10 kw for operational peaks (4-CR-1 through 4-CR-10). This requirement could easily exceed the total experiment power allocation of any given orbital facility so that operation would require shutdown of all other experiments and would absorb the several kilowatts of housekeeping loads. These power requirements are predicated on an actively cooled superconducting magnet. A substantial reduction in power demand could result if passive techniques were employed that relied on logistic resupply of a cryogen. These particular research clusters would find better accommodation potential on facility concepts with high prime power and total logistical support capabilities, such as a large space base.

The Communications and Navigation research clusters appear to present no special electrical power requirements. There will be high voltages for traveling-wave tube amplifiers and moderately high power and regulation requirements for laser experiments. The research cluster descriptions indicate electrical power requirements from a 25- to 800-w average with peaks up to 2 kw.

The Earth Observations experiment clusters operate from a group of 22 basic instruments, with each cluster requiring from 1 to 15 of the equipment items. The total connected load for these equipment items is about 5,160 w, with an approximate peak of 5,030 w for an undefined duration. The peaks are relatively small and are therefore not significant. Some of the research clusters require up to 4,800 w for operation and have a 5,520-w peak. The equipment items are also susceptible to electromagnetic interference, principally in the regions of 8 to 19.5 GHz and 450 to 600 MHz.

4.2.2 Environmental Control Subsystem

The maintenance of safe operating temperatures within individual pieces of apparatus will represent a cooling load on the environmental subsystem, an estimate of which is found in the projection of electrical power requirements. Most of the electrical energy demanded by individual instruments will be converted to thermal energy that will have to be dissipated at a rate sufficient to keep the equipment within safe operating temperature limits. Therefore, the electrical power data reflect the probable cooling load presented to the environmental control system when the duty cycle of the equipment is factored in. This is illustrated in Figure 4-4. The anomaly prominent in the Space Physics category represents the requirement to provide cooling for levitation-melting experiments in Research Cluster 4-P/C-7.

Another area of environmental control concern is that of protection of apparatus from outside sources of contamination as well as protecting and isolating the hazardous experiments from other elements of the spacecraft.

The two main sources of potential contamination are the biological materials and chemical reagents used in the Manned Space Flight Capability and Space Biology categories, and the materials used in the Physics and Chemistry investigations.

The research cluster description of cosmic-ray physics investigations reflects an active thermal cooling approach to supporting the superconducting magnet. This power demand would diminish significantly if passive techniques or logistically resupplied cryogens were employed.

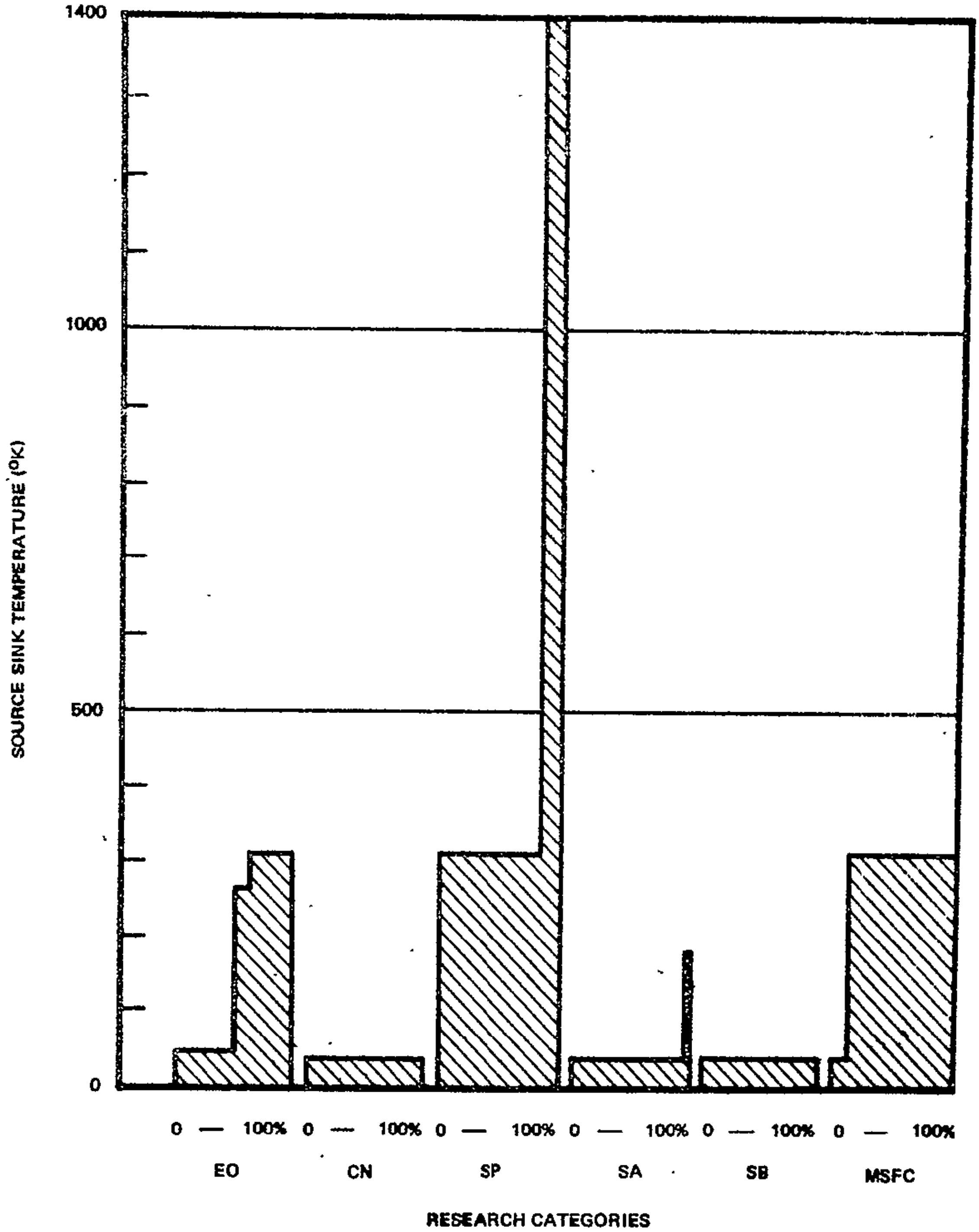

Figure 4-4. Cooling Requirements

4.2.3 Guidance, Navigation, and Control Subsystem

A review of experiment requirements reveals three critical areas in guidance, navigation, and control (GNC):

1. Maintaining extremely low acceleration levels on a space platform for extended periods of time (10^{-6} g for hours).
2. Ground-site position determination conforming to the requirements specified in certain Earth-oriented experiments.
3. Acquisition and fine pointing of astronomy experiments.

Discussions which follow attempt to define the existing problems and to point out areas requiring further study. These discussions are based upon the following findings:

1. The ambient acceleration level on a typical space research facility approaches 10^{-4} -g.
2. Sustained g-levels of 10^{-5} appear possible with passive or active devices to attenuate crew-motion disturbances.
3. Sustained g-levels of less than 10^{-6} do not appear feasible for manned space platforms.
4. Acceleration levels of 10^{-2} -g and 10^{-3} -g will require an onboard centrifuge.

Several disturbances act on a space platform to produce forces or torques, the more significant of which are:

1. Gravity gradient torques.
2. Aerodynamic drag.
3. Reaction control system (RCS) thruster firing.
4. Logistic vehicle docking.
5. Crew motion and disturbances.
6. Control moment gyro (CMG) control torques.

To illustrate the potential effects of these disturbances, acceleration levels produced by them on a 150,000-lb-class space research facility with a moment of inertia of 10^7 slugs-ft^2 are discussed briefly. Disturbances from platform rotation are computed at a 10-ft distance from the center of mass.

Gravity gradient torques are of relatively low magnitude, compared with other disturbances. Even in a worst case, acceleration produced by gravity gradient torque is well below 10^{-6} g.

The aero-torques are generally smaller than gravity-gradient torques, and they produce no significant acceleration. The largest drag force occurs at the diurnal bulge center during a period of maximum-density atmosphere. Using a vehicle of the 150,000-lb class as an illustration, the maximum expected acceleration is 0.5×10^{-6} g in a 246-nmi orbit. During periods of minimum density, gravity levels will be at least an order of magnitude lower.

While in a horizontal or belly-down orientation, a space platform rotates at orbit rate plus the control system rate within stabilization capability, which produces centrifugal acceleration of 0.46×10^{-6} g at 10 ft from the vehicle's center of mass.

For larger space platforms, such as space research facilities, RCS thrust levels are typically 100 lb. Without considering rotational effects, the g-level produced by RCS thrustor firing is 0.67×10^{-3}. The use of resistojets of the 25-millipound-thrust class for CMG desaturation allows the high-level thrustors to be inactive when low g-levels are required.

Acceleration levels produced by logistic vehicle or experiment module docking depend on docking vehicle mass, closing velocity, and docking mechanism stroke. Assuming the following parameters,

Docking vehicle mass = 1,860 slugs (50,000 lb)

Docking mechanism stroke = 1 ft

Closing velocity = 1 ft/sec (manual dock)

a linear acceleration of 6.2×10^{-3} g is obtained. Typical acceleration levels induced by rotation are

$r\ddot{\theta} = 0.62 \times 10^{-3}$g	r - distance to c.g. of vehicle
$r\dot{\theta}^2 = 0.23 \times 10^{-4}$g	$\dot{\theta}$ - angular body rate of vehicle
	$\ddot{\theta}$ - angular acceleration of vehicle

Since docking events are scheduled and predictable, and occur infrequently, they will have negligible effect on experiments requiring specific periods of low g-levels.

During experiments requiring low acceleration levels, crew motion would be limited to console operation and other similar duties. The two crew disturbances considered here are console operation and coughing, which produce both forces and moments on a space research facility. The disturbances are sinusoidal in nature at a 1- to 2-Hz frequency. This frequency is beyond the control system response range; hence, in effect, crew motion disturbances are uncontrolled. Table 4-6 summarizes typical crew-motion disturbances (maximum for console operation) for a single crew member 10 ft from the center of mass.

Minimum acceleration levels induced by console operation are approximately 10 times smaller than the maximum values. In the case of a typical space research facility where the crew numbers 10 to 12 men, the total crew motion disturbance will be greater than the values given. Determination of actual values requires an analysis which was beyond the scope of this study.

Table 4-6

CREW MOTION DISTURBANCES

	Acceleration (g)	
Disturbance	Force Component	Moment Component
Console Operation	0.5×10^{-4}	$r\ddot{\theta} = 0.5 \times 10^{-6}$
		$r\dot{\theta}^2 = 0.6 \times 10^{-7}$
Cough	0.8×10^{-4}	$r\ddot{\theta} = 0.3 \times 10^{-6}$
		$r\dot{\theta}^2 = 1.2 \times 10^{-8}$

Typically, CMG's designed for larger space platforms are capable of applying a 100-ft-lb maximum control torque. The resultant centrifugal acceleration 10 ft from the center of mass is 3×10^{-6} g. During normal operation, the control torque is not expected to exceed 5 lb, for which the acceleration is 0.15×10^{-6}g.

Figure 4-5 summarizes acceleration level and duration for the experiments that have gravity requirements and a specified acceleration level requirement. Typical disturbances are shown by vertical lines to indicate the acceleration that can be attained. The ambient acceleration environment for the chosen model is in the 10^{-4} -g range. Lower levels may be attained with unmanned modules, crew disturbance attenuation devices, or an active control system.

A system to actively control crew-motion disturbances consists of accelerometers and a mass translation system to provide control actuation. Flexible-body dynamics will present significant design problems and may limit system performance.

Since only a few experiments require low g-levels (10^{-5} or less), a trade study may reveal that the design of such an active crew-motion control system is not warranted. Higher acceleration levels would be provided by an onboard centrifuge.

Several error sources determine the accuracy of ground-site position determination from an orbiting space platform. The sources and resultant errors are:

Source	3σ Error (ft)
Space platform position with continuous ground tracking	450
Space platform position with onboard autonomous system	Current - 6,000 Ultimate - 1,800
Ground-site position relative to space platform (manual sightings)	1,500

Continuous ground tracking allows ground-site position determination within an accuracy of 1,560 ft. The accuracy associated with autonomous navigation is currently 6,200 ft and will ultimately be 2,350 ft.

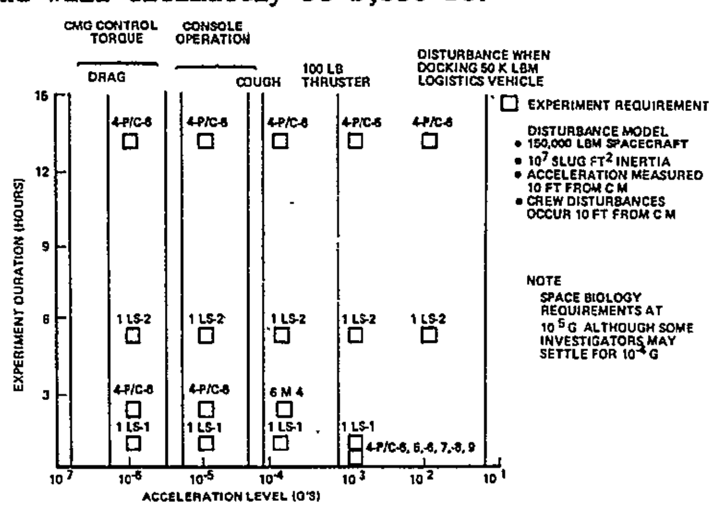

Figure 4-5. Gravity Requirements

Most Earth Observations experiments have ground-site position accuracy requirements of 3,000 and 6,000 ft, and several experiments have requirements of 100 to 500 ft and 1,500 ft. Although not specified, these requirements are assumed to be 3σ values. Ultimately, ground-site position determination requirements will be met, with two exceptions (Research Clusters 6-0-6 and 6-A/F-4). In any event, ground-site position determination requires further study. Figure 4-6 summarizes the requirements for ground-site position determination and indicates the capabilities of various systems to fulfill these requirements.

Telescope stabilization to the accuracies given in certain research cluster descriptions (3-OW, Optical Structure of Small Extended Sources, for example) is a critical area requiring considerable analysis. Various aspects of the problem (Figure 4-7) are discussed briefly.

Three basic sources of error are associated with stabilizing a telescope line of sight (LOS): (1) instrument (telescope) aberrations, (2) control system imperfections, and (3) thermal control imperfections. It would be unreasonable to burden any of the three influences with arbitrary and unrealistic (stringent) accuracy requirements. Without the benefit of exhaustive analyses, the control system accuracy requirements for the astronomy experiments are roughly estimated to be 10 percent of the overall accuracy requirements specified for a particular experiment, or as 10 percent of the resolution capability of the sensor associated with a particular experiment or research cluster. Ultimately, the control system requirements as currently defined may turn out to be more or less stringent.

A certain amount of confusion can result from the terminology used to define errors associated with stabilizing the LOS of a telescope. A definition is presented here to reduce the confusion. The term "pointing error" is the total allowable angular LOS error with respect to a desired alignment or reference. The pointing error is made up of a bias term and a random term, as shown in Figure 4-8. The random term is defined as "stability."

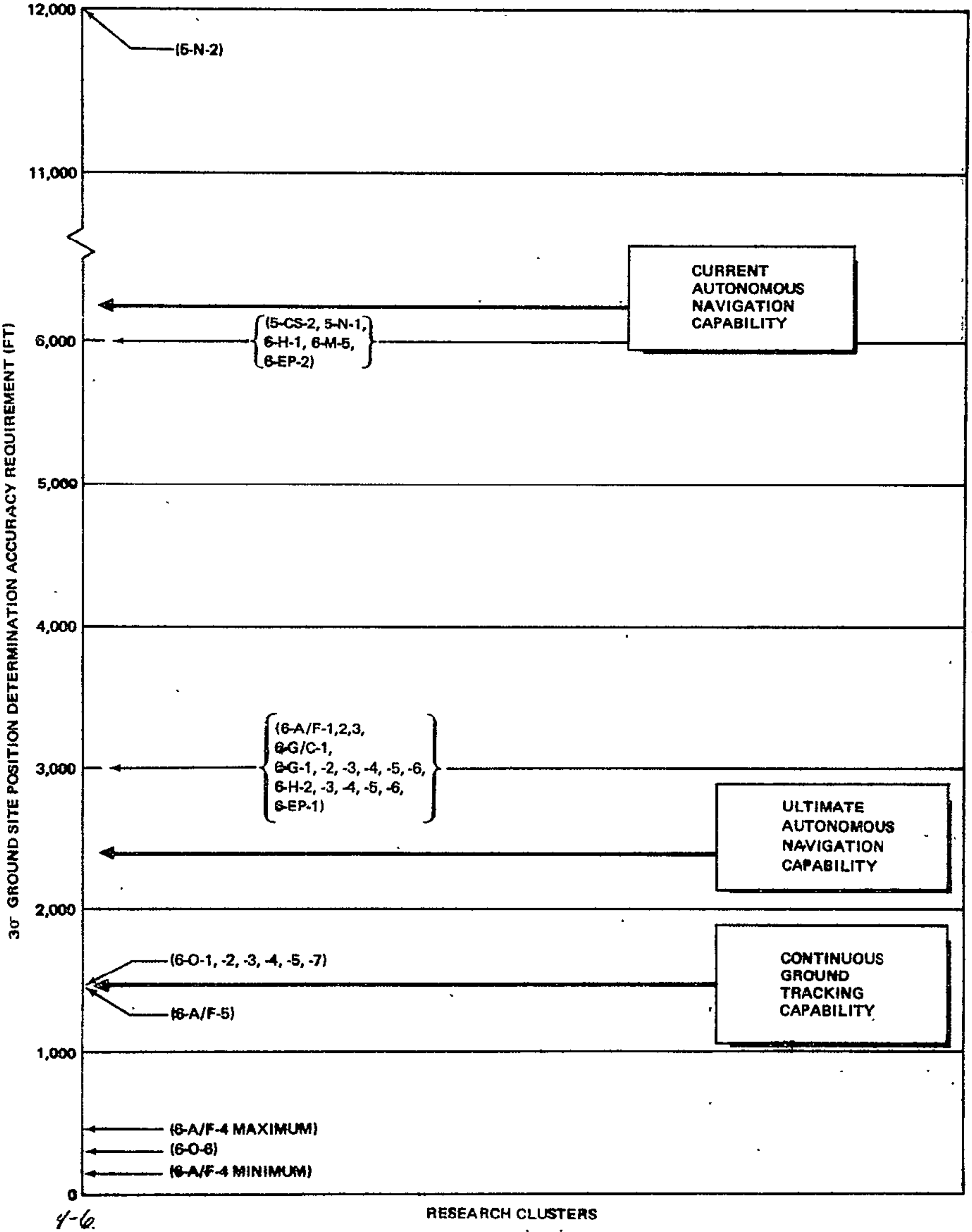

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Figure 4-6. Ground Site Position Determination Requirements and Limitations

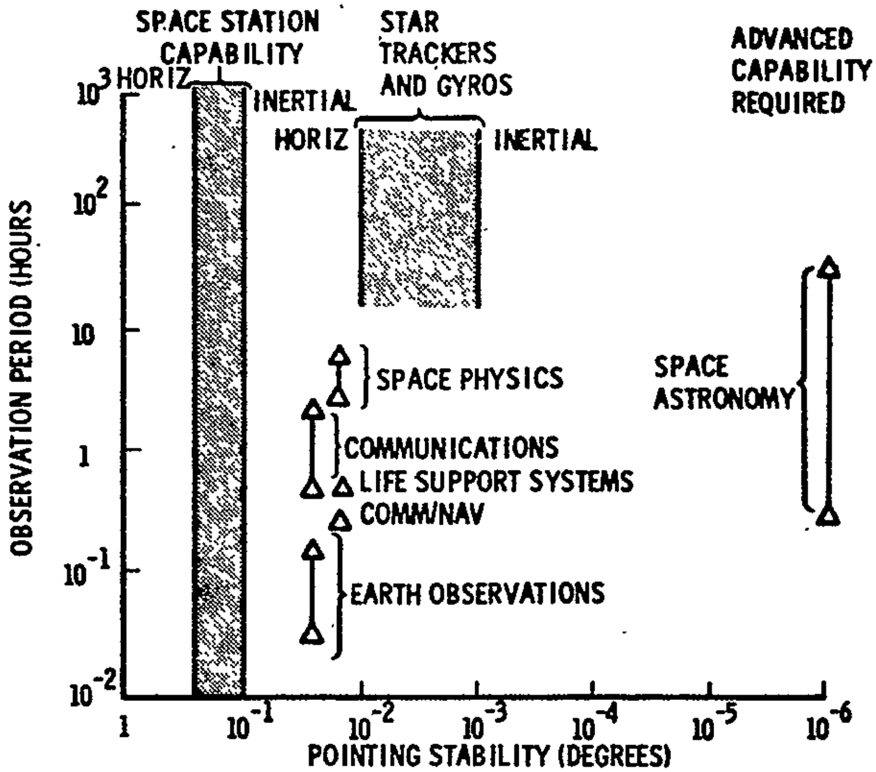


Figure 4-7. Stability and Control Requirements

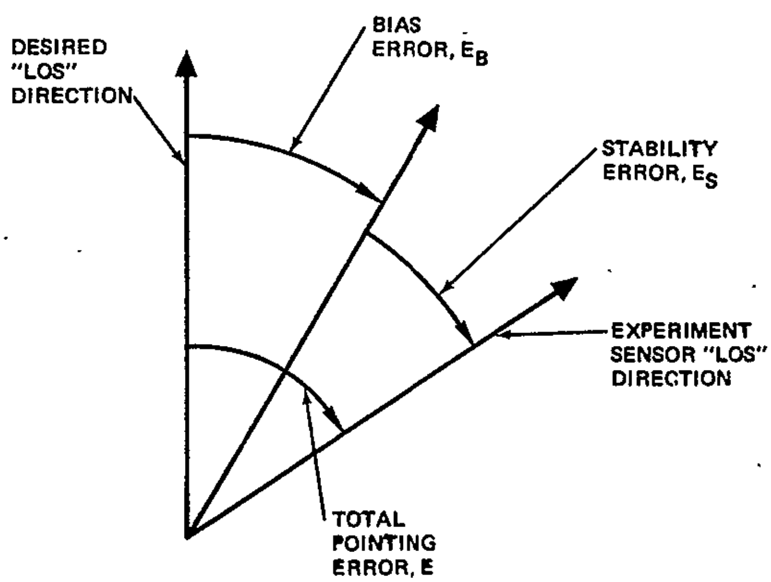


Figure 4-8. Pointing Error Geometry

Bias errors are produced by such effects as mechanical misalignment and sensor bias. Stability errors are produced by sensor and actuator noise and non-linearity, and the dynamic disturbances that act on a spacecraft or experiment module. The effects of both errors are important and must be considered in control system design. Diffraction-limited telescopes are essentially aberration-free only on the optical axis (or LOS). Therefore, a bias error causes the telescope to operate in the low-resolution portion of the field of view (FOV). Stability errors produce image motion, which results in reduced resolution through image blurring.

The stabilization requirements of many astronomy experiments are so stringent that conventional attitude sensors cannot provide the necessary accuracy. Therefore, the experiment sensor must provide attitude information. A prime example is the 3 meter, diffraction-limited telescope (the sensor for the 3-OW research cluster) with attitude-sensing capabilities, as shown in Table 4-7. These capabilities appear adequate for achieving the experiment requirements. Resolution of attitude sensing is "tighter" than the most stringent pointing requirement. The FOV for the coarse mode is larger than the pointing capability with conventional sensors (such as star trackers and gyros). Therefore acquisition, in general, should not be a difficult problem. There are experiments (photometry, for example) where objects are viewed through a slit subtending an angle as small as 1 $\widehat{\text{sec}}$. For these cases, acquisition becomes a significant problem for which techniques must be developed and analyzed.

Table 4-7

ATTITUDE-SENSING CAPABILITY OF 3-M DIFFRACTION-LIMITED TELESCOPE

Mode	FOV	Resolution	Bias Error
Coarse	1°	120 $\widehat{\text{sec}}$	300 $\widehat{\text{sec}}$
Intermediate	15 $\widehat{\text{min}}$	10 $\widehat{\text{sec}}$	30 $\widehat{\text{sec}}$
Fine	300 $\widehat{\text{sec}}$	0.005 $\widehat{\text{sec}}$	10 $\widehat{\text{sec}}$

The least complex method of control actuation consists of rigidly attaching the telescope to an experiment module or space vehicle and providing attitude control with CMG's. Unfortunately, the external and internal disturbances acting on the vehicle make this an impractical approach. External disturbances include gravity gradient torques and aerodynamic torques. Internal disturbances include crew motion in use of manned spacecraft operating machinery, antenna rotation, solar panel rotation, fans, pumps, camera shutters, focusing motors, film transporters, rotating mirrors, and other sources. The internal disturbances are not well defined as to frequency and amplitude. Therefore, uncertainty exists as to whether or not the more stringent experiment pointing requirements can be met with this technique, even with an unmanned experiment module. Alternate control actuation techniques include CMG's for the spacecraft and isolation of the telescope from spacecraft motion by magnetic suspension, gimbal systems, or movement of optical elements inside the telescope. However, these concepts have not been studied in sufficient detail to allow an accurate assessment of their capabilities.

Figure 4-9 summarizes the pointing and rate requirements for the various research clusters. The vertical lines indicate the pointing and rate capabilities of the space research facility and the Advanced OAO pointing capability. Also shown is the space vehicle capability to provide pointing and rate information to experiments that provide their own control actuation.

Requirements other than pointing and rate must be considered when selecting stabilization techniques for experiment groupings. For example, the Earth observations, (clusters 6-A/F- and the 6-O- series) have tracking requirements, conflicting viewing requirements, sensors with FOV limitations, and other requirements that will necessitate gimbaling certain experiments with respect to the space research facility.

4.2.4 Propulsion Subsystem

From the requirements analyzed, two potential major impact areas were identified in the reaction control system (RCS) area. These are (1) thrust and acceleration constraints and (2) plume contamination effects. Space Physics requirements

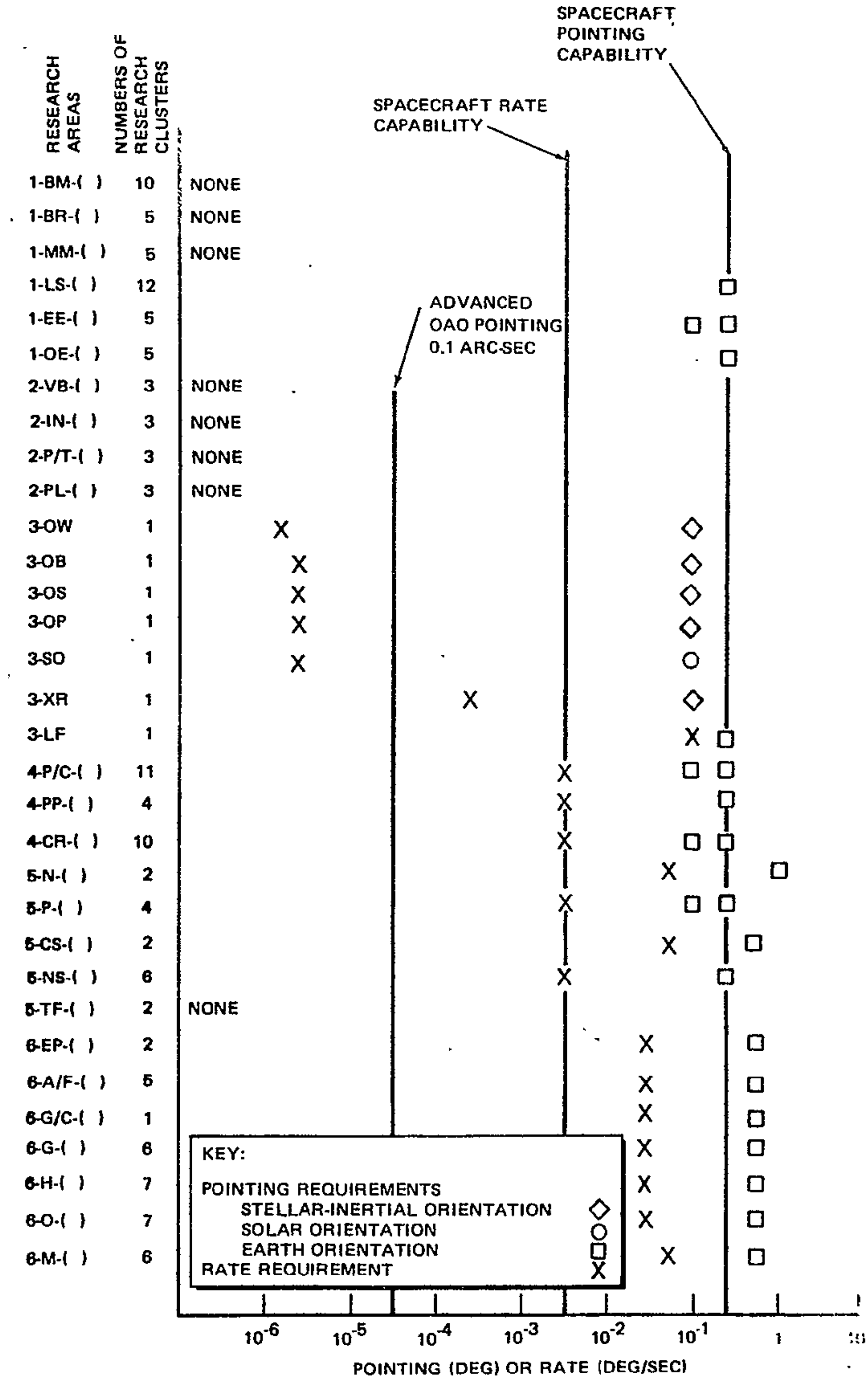


Figure 4-9. Summary of Experiment Stabilization Requirements

4-9

will be imposed on the RCS to limit accelerations to 10^{-3} to 10^{-6} g, and Earth Observations and Astronomy experiments prohibit engine effluent contamination on critical sensor surfaces. Manned Space Flight Capability investigations do not impose any specific requirements or restrictions on the RCS. In Space Biology, many investigations require g-levels in the range of 10^{-5} to 10^{-4} for extended periods. These requirements influence the mechanization and selection of RCS components.

The low acceleration-level requirements impose thrust-level constraints on the propulsion system, the severity of which is a function of vehicle weight and mission operations. For the most likely manned space programs, this constraint is not very restrictive. Selection of resistojet thrustors using biowaste gases keeps acceleration levels to 10^{-5} g while reducing or eliminating the need for propellant resupply. In addition to Space Biology experiments, the zero-g cloud chamber investigations called for in Earth observations Research Cluster 6-M-4 require this level of acceleration for extended periods of time. These research activities would benefit from a propulsion subsystem using low-thrust techniques. Unmanned experiment modules could utilize ammonia resistojet systems. Orbit-keeping and CMG saturation can be accomplished in this manner. Other propulsive functions, such as docking control and large-scale maneuvers, are performed infrequently (by a high-thrust chemical propulsion system) and can be coordinated with the experiment schedules so as not to impact any experiments. It should be noted also that some damping provisions may be required in the experiment packages for control of impulsive forces such as docking. Each vehicle and program, however, must be analyzed separately to ensure propulsion system adequacy.

The extent of plume contamination potential is one of the most important and little-understood phenomena associated with spacecraft design and contamination of critical surfaces is clearly unacceptable. Because of this criticality, coupled with a lack of meaningful data, each vehicle and experiment program combination must be analyzed separately.

4.3 DATA MANAGEMENT SYSTEM INTERFACE

Each research cluster was analyzed to determine the data support requirements. The basic results of this analysis are contained in Appendix F.

The outputs of the data management system analysis are preliminary in nature. Since few of the experimental equipments have been designed, detailed characteristics of the sensor and/or instrument outputs were not available. However, preliminary estimates were made to identify major design-influencing and pacing requirements that may be inherent in the research program.

Due to the broad spectrum of experiment program requirements (i.e., crew time, target availability, priorities, etc.), it is not enough simply to know that a group of instruments is needed to perform measurement tasks and to know each sensor's characteristic output. The following ancillary data, which will be produced from detailed design and configuration studies of the DMS in the future, are also required:

1. Operating methods and techniques are needed to define the controls and displays required for an experiment operation and also to specify the real-time data flow processing required for quality control and visibility.
2. Experiment sequencing is needed to specify the data generation duty cycles and the various modes of instrument function such as warmup, calibration, and data acquisition, and to identify and solve data traffic control and queuing problems.
3. User requirements are needed to identify real-time data-handling problems, principal investigator interfaces, information enhancement potentials, and allowable data manipulation and processing.

The complexity of measurement requirements runs from obtaining candid views of the crew to manipulating elaborate and delicate astronomical telescopes. The operational methods and techniques involved in controlling the various experiments also impose requirements on the data management system (DMS).

High-data-rate sensors, such as high-resolution TV imagers and multispectral line scanners, present severe data management problems only if their operation is frequent or nearly continuous. Experiment sequencing schedules, which indicate the frequency and duration of the observation period, permit assessment of the data generated and flexibility for rescheduling of impacting experiments.

The fundamental characteristics of information returned to the principal investigator must be identified early, during the formulation of the data system concept. The flexibility with which data can be handled, reduced, or manipulated is obtained only after a clear understanding has been gained of the required information content. Many system functions, such as storage, processing, and data delays, depend on knowledge in this area. User requirements will also identify the degree to which the principal investigator must interact with the operation and control of the experiment, including preliminary evaluation of data being generated.

These requirements are not readily identified in the conceptual stage of an experiment program. However, Subsection 5.5 examines the mission considerations that stress the importance of such information-importance not only to spacecraft data handling but also to operations planning, conceptual mission planning, crew skill mix, and overall management of onboard operations.

In summary, requirements have been identified for three levels of DMS consideration: the objective level, the mission level, and the operations level. Subsequent paragraphs discuss these three levels of requirements for the research clusters and indicate how they are used to develop system function concepts.

Research clusters provided basic objective information that was considered in isolating preliminary data-acquisition requirements. Accommodation of the broad experimental requirements will be subject to numerous iterations as improvements in component capabilities are considered, as clearer definition of objectives and priorities are made, as a fuller understanding of user needs is gained, and as the results of engineering trade studies at all levels of technical detail are analyzed.

4.3.1 Characteristics of Data Forms

Each research cluster was examined in a number of data requirement areas. The following paragraphs discuss the nature of this examination and some of the guidelines that helped to determine basic data requirements.

4.3.1.1 -Physical Format

To describe with any confidence the form that the data must be in when delivered to a user, the questions, "What will the user do with the data when he gets it?" and "What analytical functions will he perform on the data?" need to be answered.

For experiments which produce images or physical data, the investigator wants to have the image or data recorded. It may well be, however, that the user is not aware of the alternative data forms available to him.

4.3.1.2 - Precision

The quality of maintaining response fidelity to an input signal is not universally interpreted in the same way. The entry purports to be the allowable total system error, consisting of the vector sum of the individual errors. In a number of ways, the precision requirements will determine not only the sensors used but also the data management functions that can be performed on the data. The precision requirement will also determine whether and how much data reduction can be performed before the user receives the data.

4.3.1.3 - Time Allowable (Data Delay)

Effective utilization of data management principles involves consideration of the smoothing or averaging of system loading possibilities in the selection of an optimum system sizing. If data are not required by the user for significant periods of time after acquisition, the data handling loading requirements can be met by providing a temporary storage capability sized to the system queue-time and data-generation rates.

Some of the data can be characterized as being perishable. For good and sufficient reason, however, the user has expressed the need to have the data in hand within a specified period of time after collection, the periods varying from immediately after acquisition to months. The data management system, the communication system, the logistic system, and the ground system must be properly designed to accommodate these requirements.

4.3.1.4 - Raw Data Required

The term "raw data" is difficult to apply consistently to all forms of data. A photographic image, for example, can be considered raw data, both in its latent state and after chemical processing. Electrical data may or may not be considered raw data after being converted from analog data. The assumption used is that data representative of the signal sensed within the tolerance, given are considered raw. Using this definition, redundancies can be removed (a form of data compression) as long as the error of reproducibility is smaller than the measurement exactness. Data known not to contain valid information are not subject to the requirements and can be disposed of in their entirety.

4.3.1.5 - Types of Experimental Data Produced

The instruments identified in the research clusters provide (or could provide) data in many forms. In fact, experiments having several instruments provide data in several different forms. Basic forms of data are:

1. Photographic films and magnetic tape records.
2. Electrical signals.
3. Physical and biological samples or specimens.

The physical data forms analyzed onboard the spacecraft will result in secondary data forms that are different, i.e., electrical and film. These data must also be managed by the DMS.

By far, most of the data generated will consist of images in the form of photographic film (and perhaps video). When data are not required soon after collection (as defined in allowable data delay), it has generally been assumed that they have been stored on magnetic tape (if electrical).

By specifying the data form, the experiment data handling options in specific categories can be considered as each form impacts data system functions and sizing.

4.3.1.6 - Data Sensed Versus Time

The time-phased generation of data, expressed as a timeline of measurements and observations over a meaningful experimentation period, presents the operational philosophy in system language. Each research activity will likely experience at least two operating modes prior to the fulfillment of the research goals. For example, in Subsection 5.5.2, the agriculture-forestry area of research is examined for early mission activities where only truth sites are under investigation. As activities approach operational status, the observations will be made over much broader areal regions. The duration of the sequential modes will be different in each area, depending on the developmental status of experiment systems, the analytical ability to use the data, and the rate of advancement achievable.

Timeline specifics, for the most part, were not available. Those that were given were not for a significantly long enough period of time to reflect the evolutionary nature of the research. Typically, the information given was for a single operation or cycle of duty.

4.3.1.7 - Function Diagram of Data

A description of the interface between an experimental apparatus and the DMS elements is essential to analyze requirements and formulate concepts. The timeline discussed previously is an important part of the interface because data flow characteristics are a function of time.

4.3.1.8 - Data Required for Indexing

Ancillary data will have to be collected, along with all of the scientific data, for purposes of calibration, referencing, and in general, verifying that the conditions under which the scientific data were collected were within the established tolerances.

4.3.1.9 - Technology Advancements Required in Data Management

Combinations of data characteristics and handling requirements can create a desired system function that does not exist. There are two solutions for such cases. One is devising a system solution in the form of alternative functions, and the other is to embark on advanced supporting technology development (STD) programs. Because STD efforts are characteristically of long duration, it is valuable to identify potential problem areas as early as possible and to make the decision trades as soon as practicable.

Considered individually, very few experiments exhibit onboard data management STD requirements. It is not until the aggregate of payload-level requirements is considered that the data management STD requirements become large or complex enough to present problems.

4.3.1.10 - Characteristics of Electrical Data

The location and function of the interface between an experiment and the data management system were covered previously. Now a description is presented that defines the rates and/or bandwidth of each channel of data that crosses the interface. This information can be used to size system functions and to establish system computational speeds and flow rates.

4.3.2 Selected Research Cluster Analysis

Specific research clusters were selected for additional analysis to provide a cross section of the data requirements of the given science or technology category. This selection is indicative of the entire population insofar as maximum, average, and minimum data management requirements are concerned and includes the following research clusters: 1-BM-4; 1-BM-6; 1-BR-5; 1-EE-3-1; 2-PL-1, 2, 3; 3-OB; 3-OS; 3-OW; 3-XR; 4-P/C-8; 4-CR-1 through 10; 5-CS-1; 5-N-1; 5-P-2; 6-A/F-1; 6-M-1; and 6-M-2.

Summary matrices were prepared which contain the results of the analysis for the selected research clusters in each discipline. These matrix summaries, found in Appendix F, extend the data interface descriptions of the research clusters to include significant aspects of an operational program such as target cycling, observation constraints, etc., which affect data rates and quantities of onboard records. Appendix F also includes discussion of the data management characteristics of the major discipline areas, and represents a demand limit on a data management system.

The contents of the sample of research clusters is indicated by the following list:

1. Biomedical, Manned Spaceflight.
2. Behavioral Research.
3. Manned Space Flight Engineering Experiments.
4. Plant Life, Space Biology.
5. Space Astronomy.
6. Space Physics and Chemistry.
7. Cosmic Ray Physics.
8. Space Communications.
9. Agriculture and Forestry, Earth Observations.
10. Meteorology.

The summary matrices show parameters that influence data management system organization and capability. They are representative of the entire compendium of research clusters in presenting a survey of the data options available to accommodate a wide assortment of sensors. The format of the matrices has been selected to give inputs specifically tailored for data management system analysis. However, the dependency on other constraints such as scheduling, crew availability and crew skills, and other mission parameters, such as data dumps and logistical transfers, also must be considered.

The information sought in the various categories identified by the column headings differs somewhat from discipline to discipline. The following explanations of the headings will clarify their intent or define their purpose:

Group No.: research cluster number.

Group Name: cluster title.

Measurement Objective: The subobjectives of the research, expressed as targets or functions.

Indicative Phenomena: physically measurable phenomena that are translatable in data. Examples are images, spectral radiance, pressure, etc.

Resolution Requirement: spatial or spectral; the elemental resolutions of phenomena to be measured.

Target Objective: the target under investigation:

Dimensions of Target Area (Length by Width): total target dimensions (to support calculations of data loading).

Location of Target: geographical or stellar.

Replication Rate: rate of repetition of experiment cycles.

Pointing Tolerances/Stabilization Required: support for instruments sensing remote targets.

Preferred Inclination/Altitude: inclination and altitude requirements indicated by target location and sensor capability.

Illumination: acceptable sun angle for Earth-oriented experiments, or intrinsic radiated power.

Critical Schedule Factor: a time variable used for scheduling experimental activities and data taking; a measure of the allowable schedule variation to permit planning flexibility.

Cloud Cover Maximum: acceptable cloud cover over the target area; applies to Earth observations only where the sensed radiation cannot penetrate clouds.

Experiment Operating Duration: expected duration of the experimental activity.

Observation Cycle: the length and repetition rate of the observation cycle with respect to other experimental operations.

Crew Functions Involved: listing of the crew functions required to support the experimental data management system operations.

Selected Instrumentation: sensors or experiment equipment employed. These are numbered for further use elsewhere on the matrices.

Up to this section of the matrix, information required for the matrices was oriented toward experiment definition, operating characteristics, and constraints. Further information needed involves data generated by the experiment. The next five columns are general data requirements and are keyed to the experiment measurement objectives, which are represented by the rows of the matrix. The remaining columns are sensor-oriented and are keyed to the sensor identification number (Task/Instrument Key). The sensor-oriented data are separated into major headings of Electronic Data or Film Data. The remaining column headings are:

Sensor Output Data Form: the basic form of the data prior to extensive processing.

Principal Experimenter Information Requirement: the useful information anticipated from the experiment data. Examples are crop identification, mapping, etc.

Principal Experimenter Requirements (Allowable Time Delay): the permissible time delay between data collection and delivery to the principal investigator.

Onboard Display Requirements: the types and numbers of onboard displays required for experiment operation, control and data verification.

The next seven columns come under the major heading of Electronic Data, with the first three addressing the data rates for the operational modes of data acquisition (Calibrate, Target Acquisition, and Operate). The last four columns under Electronic Data involve schedule versus information, plus a space for remarks.

The last major heading is Film Data. For those sensors that generate data on film, this section contains information similar to that under Electronic Data, plus logistic considerations.

Completing all the entries in the matrix would supply not only sufficient information to quantify the data generation characteristics, but also enough operating and sequencing data to synthesize total research cluster requirements and to quantify a mission data acquisition function. Additional bounding criteria are necessary to fully quantify all of the data management functions. These criteria include:

1. User requirements.
   A. Interaction with control and evaluation.
   B. Information needs.
   C. Real-time requirements.
   D. Data processing requirements.
2. Experiment program scheduling, showing initiation and end points of each experiment operation.
3. Short-term scheduling, showing the daily, weekly, or monthly operation.
4. Operational definitions.
   A. Experiment-crew interfaces.
   B. Skill levels required.
   C. Controls and displays.

The 18 summary matrices (see Appendix F) provide a cross section of data requirements needed to proceed to a system-level synthesis in data management system and experiment control for all 18 research clusters. Table 4-8 summarizes some of the more pertinent data contained in the detailed interface descriptions.

4.3.3 Summary Conclusions

Significant conclusions reached in the course of analyzing DMS requirements include:

A. No individual experiment represents a constraining impact on the DMS.

B. The biomedical, behavioral, and general performance experiments are sampled at periodic intervals and represent an order-of-magnitude less data than previously determined. The reduction is due to better definitions of data cycle as opposed to experiment duty cycle.

C. The earth observation instruments represent the greatest potential for data management impacts. High-resolution data required for large geographical areas calls for an average of 2,500 resolution elements per square mile. Coverage area has not been specifically defined but the following table lists categories of areas of interest:

	Area (sq mi)	Average Resolution (ft)	No. of Resolution Elements
World land	58×10^6	100	15.7×10^{10}
Oceans	139×10^6	100	37.5×10^{10}
U. S.	3×10^6	100	8.1×10^9

The conversion of resolution elements to digital bits will increase the numbers by a factor of seven.

D. Analysis of initial operation of earth resources sensors indicates a severe operational restriction due to limitations of target availability.

E. Operational analyses performed on the 1-BM series of research clusters (see Subsection 5.5.2.3) indicate that scheduling and timelines will significantly affect support systems.

Inasmuch as no individual research cluster constrains the DMS, a matrix chart showing DMS functions for each major research cluster was prepared to identify the commonality of DMS functions among all clusters (Table 4-9). First, it

Table 4-8

DATA ACQUISITION INTERFACE SUMMARY MATRIX

Cluster No.	Data Acquisition Mission Period	Relative No. of Instruments	Investigator's Requirements	Transport Delay	Onboard Displays			Onboard Storage			Data Acquisition		
					CRT	Chart	Dial	Film	Magnetic Tape	Sample	Period	Repeat	Rate
1-BM-4	Entire mission	6	Mission trends	3 days	✓			✓	✓		1 to 3 min	3 days	TBD(3)
1-BM-6	Entire mission	15	Mission trends	3 days	✓	✓	✓		✓		30 min	3 days	TBD(3)
1-BR-5	Entire mission	4	Mission trends	7 days							1 hr	1 week	TBD(3)
1-EE-3-1	TBD	5	Performance data	End of cycle (2)							4 hr	TBD	TBD(3)
2-PL-1,-2,-3	Entire mission	12	Specimen data	End of mission	✓			✓	✓	✓	30 min	3 days	TBD (3)
3-OB	2 yr	5	Imagery	End of cycle (2)			✓	✓	✓		1 min	Cont	TBD (3)
3-OS	1 yr	5	Spectrograms	End of cycle (2)			✓	✓	✓		1 hr	Cont	TBD (3)
3-OW	2,000 hr	7	Imagery	End of cycle (2)	✓		✓	✓	✓		10 hr	Cont	TBD (3)
3-XR	Entire mission	7	Spectrograms	End of cycle (2)	✓		✓	✓	✓		Cont	Cont	TBD (3)
4-P/C-8	600 hr	8	Specimens	End of mission			✓			✓	10 min	Cont	TBD (3)
4-CR-1→10	3 mo(1)	11	Spectrograms	End of mission	✓		✓		✓		Cont	Cont	TBD (3)
5-CS-1	2 yr	6	Parametric data	End of cycle (2)	✓	✓	✓		✓		1 sec	Cont	TBD (3)
5-N-1	3 mo	7	Parametric data	End of cycle (2)	✓		✓		✓		1 sec	1/2 day	TBD (3)
5-N-2	1 yr	7	Parametric data	End of cycle (2)	✓		✓		✓		1 min	1 day	TBD (3)
5-P-2	2 yr	3	Parametric data	End of cycle (2)	✓		✓		✓		10 min	1/2 hr	TBD (3)
6-A/F-1	1 yr	3	Maps and signatures	End of cycle (2)	✓		✓	✓	✓		15 min	TBD	TBD (3)
6-M-1	TBD	7	Isograms	1 mo	✓				✓		10 min	TBD	TBD (3)
6-M-2	1 yr	2	Maps	End of cycle (2)	✓			✓	✓		30 min	1 day	TBD (3)

Notes.

(1) Requires reconfiguration after observations are made for this period and prior to activation of subsequent observations.
(2) Investigators need data after completion of major mission cycles, i.e., logistics resupply.
(3) Data acquisition rate can only be defined after preliminary design has been completed of the sensor/DMS electrical or mechanical interface.

TABLE 4-9

DATA HANDLING AND SUPPORT REQUIREMENTS FOR ALL RESEARCH CLUSTER GROUPS

Research Cluster		Location			Original Data Form										Data Conditioning			Data Buffering			Data Processing					Storage			Display				Control					Support Services						Crew Time			
No.	Title	Integrated	Attached	Free Flying	Hardcopy, Notes	Specimens, Samples	Voice	Film/Plates	Magnetic Tape	Digital	Analog	Video	Remarks	Film Processing (Note 1)	Analog Electronic	Digital Electronic	Within Experiment	Within DMS	Digital	Analog	Preprocessing	Redundancy Removal	Evaluation	Computation	Trafficking	Analog	Digital	Physical	Alpha-Numeric	Image	Analog	Special Purpose	Preprogrammed	Adaptive/Manual	Nonadaptive/Manual	Remote	Sequencing	Pointing/Stabilization	Environmental Control	Resupply	Onboard Checkout	Rendezvous and Dock	Concurrent Ground	Specialist	Highly-Trained Nonspecialist	Nonspecialist	
1-BM	Biomedical	o			o	o	x	o	x	x	o	o			o	o	o	x	x	o	o	o	o	o	o	o	o	o	x	o	o	o		o	x				o	o	o			x	x		Manned Spaceflight Capabilities
1-BR	Behavioral	o			o			x	o	o	o	x			o	o		o	o		o	o	o	o	o	o	o	o	o	o		o		o	x				o		o			x	x		
1-MM	Man's Performance	o			o		o	o	o	o	o	o			o	o	o	o	o		o	o	o	o	o	o	o	o		o			o		o				o						o		
1-LS	Life Support	o			o		o		o	o	o				o	o	o	o	o		o	o	o		o	o	o	o	o					o	o				o	o	o				o		
1-EE	Man and Systems	o		o	o		o	o		o	o			o	o	o	o	o	o		o	o			o		o		o					o	o			o			o				o		
1-OE	Operations	o		x EVA	o	o	o	x		o	o	x		x	o	o		o	o		o	o			o		o	o						o	x	o			o				o		o		
2-IN	Invertebrate Biology	o		o	o	o	o		o	o					o	o		o	o		o	o			o		o	o						o					o	o				x			Space Biology
2-PT	Plant Biology	o			o	o	o			o															o			o	o					o					o	o				x			
2-VB	Vertebrate Biology	o			o	o	o	o		o	o				o	o	o		o		o	o			o		o	o							o				o	o			o	x	o		
2-PL	Plant Biology	o			o	o	o	o		o	o				o	o	o		o		o				o		o	o	o						o				o	o				o			
3-OW	High-Resolution Astronomy			o			o	x		o	o	o			o	o	o	o	o	o	o	o			o			o	o	o		o			o	x		x		o		o		x			Astronomy
3-XR	X-Ray Astronomy			o			o	o	o	x		o				o	o	o	o	o	o	o			o	o	o	o	o	o					o	x		o		o		o			o		
3-LF	LF Radio Astronomy			o			o			x						o	o	o	o		o	o			o		o		o						o	x		o				o			o		
3-OB	High Resolution Planet Astronomy			o			o	o		o		o				o	o		o		o				o		o	o	o	o		o			o	x		x		o		o		o			
3-OS	Astronomy Surveys			o			o	x		x	o	o		o		o	o	o	o		o	o			o		o	o	o	o			o		o	x		x		o		o		o			
4-PC	Space Physics	o			o		o	o		o	o	o			o	o	o		o		o				o		o	o	o	o						o			o	o				o			Space Physics
4-PP	Plasma Physics			o			o	o	o	o	o	o			o	o	o	o	o		o	o			o	o	o	o	o	o					o	o		o				o		o			
4-CR	Cosmic Ray Physics	o	o		o		o	o		o	o				o	o	o	o	o		o	o		o	o		o	o	o					o	o	o		o	o	o				o	o		
5-N	RF Noise	o					o	o	o	o	o				o		o	o	o	o					o			o			o	o	o		o			o		o	o				o		Communications and Navigation
5-P	RF Multipath	o					o		o	o	o				o	o	o	o	o		o		o	o	o	o	o		o		o	o	o		o								o		o		
5-TF	Communication-Navigation Facility	o					o			o	o	o			o	o	o		o	o	o				o				o	o		o			o			o	o	o				o			
5-CS	Millimeter Wave Demonstration	o					o			o	o				o	o	o		o		o				o		o		o						o			o					o		o		
5-NS	Navigation Systems	o					o		o	o	o	o			o	o	o				o				o	o			o						o			o							o		
6-AF	Agriculture-Forestry		o				o	x		x				x		o	o	o	o	o	o				o		o	o	o	o		o		o	o	o		o		o	o		o		o		Earth Observations
6-GC	Photo/Multisensor Mapping		o				o	x	o	x				x		o	o		o		o	o			o		o	o						o	o	o		o	o	o			o		o		
6-EP	Earth Photography		o				o	x		x				x		o	o		o		o	o			o		o	o	o				o	o	o	o		o	o	o	o		o		o		
6-G	Geology		o		o		o	o	o	o		o		o		o	o	o	o		o	o			o		o	o	o	o				o	o	o		o	o	o					o		
6-H	Hydrology		o				o	o	o	o		o		o		o	o	o	o		o	o			o		o	o	o	o				o	o	o		o	o	o			o		o		
6-M	Meteorology		o				o	o	o	o	o			o	o	o	o	o	o		o	o			o	o	o	o	o					o	o	o		o	o	o					o		
6-O	Oceanology		o				o	o	o	o	o			o	o		o	o	o	o	o	o			o	o	o	o	o	o				o	o	o		o	o						o		

LEGEND

Key: o Nominal Requirement
x Significant Requirement

Commercial Quality TV

Video or Film

Visual Evaluation

Visual Analysis

Note 1: Onboard Film Processing is not a Firm Requirement. Implementation will require a Development Effort.

identifies each experiment grouping as a free-flyer, attached module, or integrated experiment. Secondly, it identifies commonality of original data forms. Further, columns on the chart identify common requirements for onboard data processing, storage, display, and control. The scope of the DMS activities in this study defined in a preliminary fashion the characteristics of sensor groupings to look at identified sensor and data forms and in selected cases developed examples of the analytic processes which define the transition from sensor definition to system requirements definition.

4.4 CREW REQUIREMENTS

An analysis was performed to identify the crew requirements of the experiment program in terms of the conduct or support of specific experiments. The data required for a definition of the crew requirements include crew task identification, task time, type and level of skill, interfacing equipment, unusual environments under which tasks are conducted, and the needs for selection, training, and scheduling of onboard manpower. For long-range planning of a complex orbital experiment program, crew requirements become especially critical because of the impact on space vehicle sizing, mission timelines, and crew selection and training criteria.

The study identified the extent of crew participation required in each experiment area, and relevant crew data were included in the research cluster descriptions.

4.4.1 Analytic Procedure

Identification and description of Crew Requirements was performed using as a base the Research Cluster descriptions. These descriptions contain data on research activity, experiment scheduling, and experimental equipment operation, all of which are helpful in determining crew tasks, skill requirements, task times and frequencies, and special crew requirements. Crew tasks required for each Research Cluster were identified and placed into one of nine activity categories (e.g., experimental subject, spacecraft operations, conduct experiment, evaluate results, etc.). Crew skills were derived by examination of the type of activity and analysis of the background or training needed to perform the specific task. Task time estimates were based on time required to perform the same or similar tasks on the ground. Table 4-10 summarizes, for each experimental discipline, the types of crew activity required, the percentage of task time devoted to each major activity type, and total man hours required. These data should not be construed as representative of the magnitude of the research program, nor indicative of the relative crew involvement between disciplines. Rather they provide an estimate within each research area of the relative distribution of activities required in the conduct of a substantive research program in the specific discipline.

Each experimental task was analyzed to determine the type of skill and the level of skill required to perform the task. Skill type was divided into the 20 categories shown in Table 4-9, each type representing the range of skills normally associated with a particular discipline. Three skill levels were identified each of which described the specialized education or training required for task performance. The highest skill level (I) requires extensive education and training in a professional discipline, usually representing a Master's or higher degree in the discipline. The intermediate, or technician level (II), requires several years of training in the discipline, but not necessarily a formal degree. Level III skill is that which can be achieved through cross training in three months or less by crew members not having specific background in the discipline. The distribution of skills for each of the three levels is shown in Figure 4-10 along with the number of research clusters involved. Table 4-11 summarizes relative requirements for EVA and IVA.

The basic worksheets for each research cluster contain entries identifying points in time for a nominal experiment protocol to be initiated and the duration in years for which it would be reasonable to expect the typical experiment to continue. These worksheets, which can be found in Appendix C of this report, were found useful in evaluating the capability of planned vehicles to accommodate the experiment program, determining required crew size and skill mix for specific vehicles or crew cycles, and in making tradeoff decisions in selecting experiments to fly at a particular time.

Table 4-10

TYPES OF CREW ACTIVITY REQUIRED

Type of Activity	Bio-Medicine	Man-Systems Integration	LS and Protective	Engineering Experiments	Operations Experiments	Space Biology	Space Astronomy	Space Physics	Comm/Nav	Earth Observations
	Crew Requirement by Experimental Discipline									
1. Experimental Subject	16%	38%	0%	13%	6%	<1%	0%	0%	0%	0%
2. Spacecraft Operations	0%	<1%	<1%	3%	3%	0%	7%	<1%	28%	<1%
3. Pre- and Post-Experiment Operations	25%	18%	5%	7%	13%	14%	11%	1%	21%	38%
4. Maintenance of Apparatus	5%	8%	7%	4%	<1%	8%	5%	1%	9%	7%
5. Conduct of Experiment	42%	22%	73%	57%	58%	68%	77%	98%	24%	20%
6. Visual Observations and Data Evaluation	12%	14%	15%	16%	20%	10%	<1%	<1%	8%	35%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
(Man-Hours Base)	(11,961)	(8,145)	(5,449)	(4,992)	(5,977)	(7,600)	(990)	(22,898)	(6,457)	(63,427)

4.4.2 Crew Involvement by Experiment Discipline

The level of crew involvement varies greatly between experiment and disciplines, ranging from highly automated systems, which require relatively little crew attention, to hardware and experiments which require nearly full-time manning. The general level of crew involvement in each experiment area is summarized below.

A. Biomedicine - Most of the biomedical experiments require extensive crew participation since crewmen will be utilized both as experiment monitors and experiment subjects. Those experiments involve the effects of radiation and toxicology on instrumented animals.

The skill level II investigator plays an indispensable role in the experiment program. The experiment setup, including subject preparation, usually requires the participation of an individual experienced and knowledgable in physiology. The conduct of the experiment, particularly when a preliminary evaluation of data validity is involved or when blood sampling is part of the experiment regimen, requires the same experience level. Cross-trained skill level III crewmen may be utilized for the more simple experiment preparations and postrun cleanup. The experiment subjects, although primarily crewmen, in most cases must be thoroughly trained in the experimental techniques during the establishment of preflight baselines. The skill level I investigator is required in only a few research clusters and then only for a minimum of tasks.

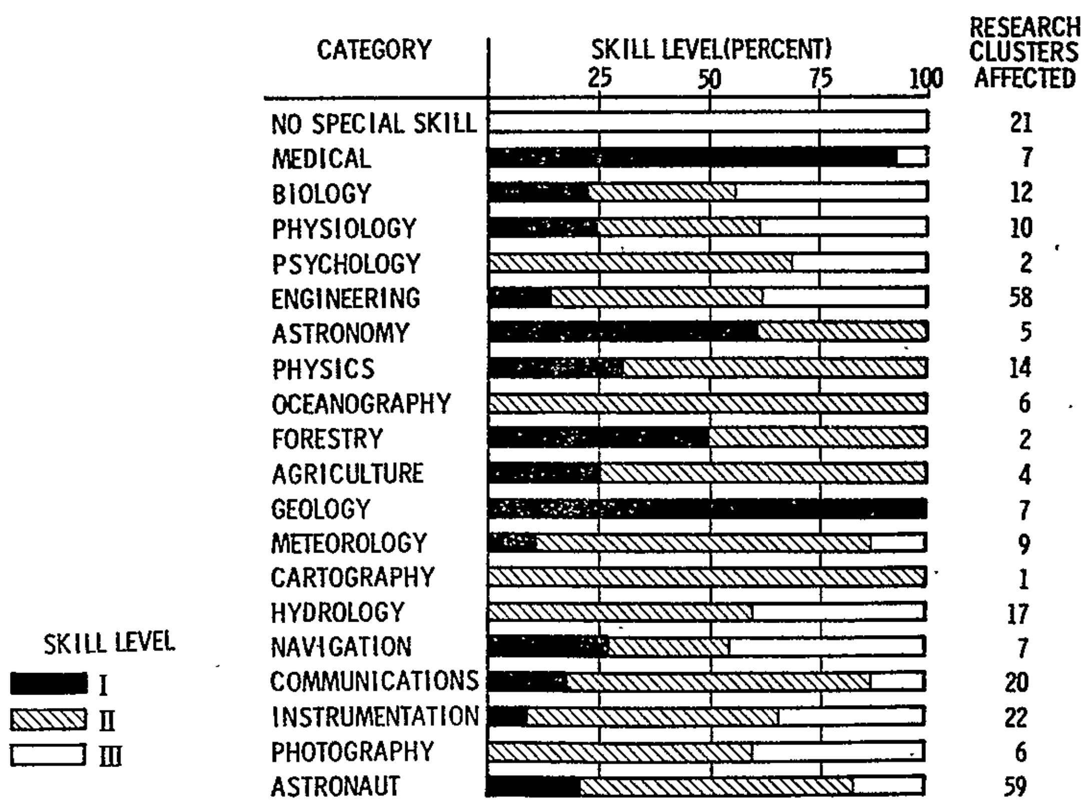


Figure 4-10. Distribution of Experience Levels

Table 4-11

RELATIVE DISTRIBUTION OF EVA AND IVA

Discipline	EVA	IVA
Biomedicine	0%	100%
Man-Systems Integration	0%	100%
Life Support and Protective Systems	<1%	>99%
Engineering Experiments	<1%	>99%
Operations Experiments	<1%	>99%
Space Biology	0%	100%
Astronomy	77%	23%
Space Physics	0%	100%
Communications and Navigation	<1%	>99%
Earth Observations	3%	97%

Before flight, instrumented animals will be prepared for automated data production and will require only minimum monitoring and general maintenance from a crewman.

The exposure of mice and rats to radiation and toxic contaminants, and the treatment of experimental lesions will require, at least, a skill level II crewmen with significant experience in those specific activities. The analytical chemical laboratory will be manned by an individual of similar experience.

B. Man-Systems Integration - In general, these experiments are addressed to evaluation of man's behavior as an individual, in a group setting, and at the interface with hardware. As such, they require heavy participation by the crew as experiment subjects. The crew is also involved in setting up conditions for individual experiment runs and in the operation, monitoring, and maintenance of experiment measurement equipment. In many of the man-systems integration experiments, the manned activities observed are regularly scheduled mission tasks and thus will not impose an additional requirement on crew time as experiment subjects.

C. Life Support and Protective Systems - The nature of the specific experiment determines level of crew involvement. Basic heat and mass transport experiments are shorter in duration (minutes to hours), but require setup, startup, data taking, and continuous observation by at least one crew member. Evaluations of complete life support systems and subsystems extend over long durations (weeks to months) and require close monitoring only during startup, but once in operation, they depend heavily on automatic data recording, testing, and controls. The crew must follow a daily schedule of monitoring and must perform weekly equipment maintenance. Onboard data evaluation both from direct observation during runs or from recorded tape will also be required for immediate assessment of results.

D. Engineering Experiments - All these experiments are concerned primarily with the evaluation of hardware and do not require the crew as experiment subjects except for Data Management experiments where man serves as an experiment subject while interfacing with the subsystem hardware. Engineering at skill Level II predominates for these experiments, with a minor requirement for navigation and communications skills. For several of the engineering experiments, support is required from the astronaut crew in controlling and maintaining the vehicle in attitude, velocity, and torque disturbances. For the most part, data collection is automated, with the crew providing a monitoring function to assure that instrumentation is operating properly. An important crew function for most of these experiments is periodic reconfiguration of experiment equipment setups.

E. Operations Experiments - The objective of these experiments is to evaluate mission operations as a complex of hardware, procedures, and crew skills. The crew will serve as experimental subjects in most of these experiments. However the crew time required for these investigations will not be an additional burden since these are operations such as the setting up and monitoring the operation of measurement equipment and the recording, collation, assembly, storage, and transmittal of data which will be performed onboard in any event.

F. Space Biology - This research program has been divided into the following four specimen-oriented research clusters: vertebrates, invertebrates, plants, and protists and tissues, each with a preliminary phase, intermediate phase, and advanced phase. The preliminary phase of all clusters is directed toward the initial investigation of general phenomena and will involve extensive automation of observations requiring minimal crew participation. The nonautomated tasks associated with this phase, such as the preservation of specimens, the identification of developmental abnormalities, and the separation of individuals according to sex are neither time consuming nor complex and may easily be accomplished by a cross-trained crewman.

The intermediate phase is characterized by experimentation in those phenomena for which alterations due to the space environment are indicated. Such experiments will necessitate real-time observations in an onboard laboratory rather than postflight analysis on returned specimens. The laboratory analyses are expected to involve standard procedures and instruments modified for spacecraft use. They will, however, make increased demands on the experimenter's time, and will require the experience of at least a semiprofessional investigator. The assignment of this individual to space biology research on a near full-time basis should be anticipated with the part-time assistance of two cross-trained crewmen.

The advanced phase of the research program will involve a detailed examination of the mechanisms responsible for the observed changes. Although the changes to be examined are unknown at present, it can be predicted that the investigation will require sophisticated techniques and a flexibility of investigative approach and direction. The on-board presence of a principal investigator, or at least a research biologist assigned full-time to the laboratory, is required to meet the criteria of this advanced phase. The full-time assistance of cross-trained crewman also should be anticipated.

G. Astronomy - These experiments generally involve long data-taking periods which are automated to a high degree and consequently require minimal crew activity. The crew will be required to unpackage and activate the experiments initially, periodically calibrate and check out the hardware, and perform servicing and maintenance functions. The predominant skill levels required will be I and II considering the sophistication of the astronautical instruments.

H. Space Physics - Some of these experiments are performed within the space vehicle and some are performed with free-flying vehicles released from the space laboratory. For the latter, crew involvement includes assembly, deployment, and retrieval of experiment equipment through the scientific airlock. For all experiments, the crew will set up and check out the experiment, and perform maintenance as required. During the automatic data-taking phase, the crew will monitor the operation periodically and change film magazines, filters, and lenses as required. When unexpected events occur, the crewman will be required to operate equipment manually for short periods of time. Film will be processed onboard, and a quick-look analysis will be performed to check data quality. Consumables must be resupplied, and maintenance and calibration performed as required. The majority of onboard crew support will require a skill level II.

I. Communications and Navigation - Crew involvement is heaviest at the initiation of these experiments for installation, calibration, and initial setup of the experiment. For some of these experiments, crew EVA will be required at the outset in performing such tasks as erecting, assembling, and visually inspecting antennas, components, feeds, and test equipment. During automated data collection, crew participation will include monitoring of experiment operation and the collection of data, monitoring and control of the remote maneuvering satellite (RMS), and adjustment of experiment equipment as required. An extremely important function to be performed by the crew is periodic reconfiguration of experiment equipment either as a scheduled event or in response to conditions which the experimenter observes during the conduct of experiments. The experimental activities in this area will require approximately an equal mix of skill levels I, II, and III.

J. Earth Observations - The crew is required to set up these experiments initially and to reconfigure the equipment periodically. During experiment operation, the crew will be required to start the photographic sequences and to locate and photograph targets of opportunity. The crew is also required to change film, service and maintain the equipment, and process the film. Approximately an equal mix of skill levels I and II will be required.

4.4.3 Conclusions

The methodology employed in the analysis of crew requirements for this study is typical of approaches to problems of this kind and is quite adequate as a methodology. The detailed results of the analysis, however, should be viewed with caution and should be considered more as approximations than as hard data. They do, however, serve a useful purpose by providing a basis for rough order-of-magnitude comparisons of the crew requirements for different types of experiments.

Crew task times and experiment scheduling data are perhaps most subject to change, while higher confidence is felt in the identification of tasks, the frequencies with which they are performed, and the skill levels required. It is desirable, if not mandatory, that authors of experiments should be asked, even in the initial conceptual design phase, to consider and identify both the projected time at which an experiment should be started (calendar time or number of years from some base) and the duration of the experiment in years once it is started. These estimates should be subject to iterative review and updating as the experiment programs evolve. The accurate identification of task times is a much broader problem and is common to all analysis of this type. What is needed is a centralized data base of task data obtained from empirical observations (in either simulated or real environments) to the extent possible, supplemented by the best available estimates from experts such as the astronaut population.

Data of the type presented in this section can be extremely useful in mission planning by answering such questions as (1) whether it is possible or economically feasible to do a particular experiment with available vehicles, crews, and schedules, (2) what training time is required to prepare for inflight experiments, (3) what crew sizes and skill mixes are required to do all or a selected portion of proposed experiments. It can provide assistance in scheduling experiments over an extended time period and can define design requirements for vehicle systems in terms of control/display needs, EVA requirements, and data handling loads. Additional usefulness of the data can be derived by manipulatio using techniques under development such as the Langley Research Center's Space Station Mathematical Model. The development of such techniques must start with a valid task-and-skills data base and with the enunciation of basic ground rules relating to such variables as skill, skill mix, and cross training, at the professional level.

4.5 SUMMARY OF RESEARCH CLUSTER WEIGHT, VOLUME, AND POWER REQUIREMENTS

Preliminary estimates of experiment equipment weight, volume, and power for each of the research cluster descriptions is listed in Table 4-12. The primary instruments were identified in the research cluster descriptions. In many cases, the precise description of the apparatus was not determined, and only a conceptual volume and weight estimated. In other cases, the space hardware configuration has not yet been conceived, but technical catalogs list the equivalent nonspace-qualified devices having similar operating characteristics. These items of equipment were generally taken at the catalog size, weight, and power, and as such should be considered an upper limit to the summary estimates. There may be considerable change in the mass properties as the technical configurations for space-use evolve.

Table 4-12 (Page 1 of 6)

ESTIMATES OF INSTRUMENT CHARACTERISTICS

Research Cluster	Weight (Lbm)	Volume (Ft^3)	Average Power (Watts)
Biomedical			
1-BM-4	1,570	85	100
1-BM-5	3,600	340	240
1-BM-6	1,810	150	350
1-BM-7	1,120	60	1
1-BM-8	1,075	70	40
1-BM-10	1,265	60	200
1-BM-12	3,350	280	100
1-BM-13	1,380	80	50
1-BM-14	460	40	20
1-BM-15	1,550	1,765	280
Behavioral Research			
1-BR-1	6,035	2,870	180
1-BR-2	1,345	70	50
1-BR-3	1,000	50	47
1-BR-4	2,270	1,765	200
Man-Machine			
1-MM-1	1,300	120	50
1-MM-2	1,280	100	40
1-MM-3	1,155	80	40
1-MM-4	2,170	350	100
1-MM-5	350	25	345
Life Support and Protective Systems			
1-LS-1	300	8	200
1-LS-2	500	30	800
1-LS-3	600	24	1,000
1-LS-4	400	20	100

Table 4-12 (Page 2 of 6)

ESTIMATES OF INSTRUMENT CHARACTERISTICS

Research Cluster	Weight (Lbm)	Volume (Ft^3)	Average Power (Watts)
1-LS-5	450	50	700
1-LS-6	2,500	100	1,000
1-LS-7	300	32	300
1-LS-9	900	100	500
1-LS-10	700	40	1,000
1-LS-11	1,200(1)	1,000(1)	100
Engineering Experiments			
1-EE-1	2,800	70	100
1-EE-2	800	6,510	550
1-EE-3	1,170	34	530
1-EE-4	910	33	100
1-EE-5	660	42	50
Operations Experiments			
1-OE-1	940	61	400
1-OE-2	1,700	110	200
1-OE-3	TBD	TBD	TBD
1-OE-4	TBD	TBD	TBD
1-OE-5	TBD	TBD	TBD
Vertebrates			
2-VB-1	3,610	5,265	450
2-VB-2	3,610	5,265	450
2-VB-3	3,610	5,265	450
Invertebrates			
2-IN-1	2,670	5,160	80
2-IN-2	2,435	5,140	80
2-IN-3	3,245	5,170	80

(1) For entire facility.

Table 4-12 (Page 3 of 6)

ESTIMATES OF INSTRUMENT CHARACTERISTICS

Research Cluster	Weight (Lbm)	Volume (Ft^3)	Average Power (Watts)
Protists and Tissues			
2-P/T-1	1,820	5,160	440
2-P/T-2	1,670	2,060	480
2-P/T-3	3,220	5,170	590
Plant Life			
2-PL-1	3,180	4,880	265
2-PL-2	3,180	4,880	265
2-PL-3	3,180	4,880	265
Astronomy			
3-OW	26,500	9,520(2)	930
3-XR	7,640	7,360(2)	406
3-LF	1,410	54(2)	366
3-OB	27,030	9,665(2)	100
3-OS	530	145(2)	170
Physics/ Chemistry			
4-P/C-1	350	51	750
4-P/C-2	1,480	55	400
4-P/C-3	1,800	64	30
4-P/C-4	580	28	5,000
4-P/C-5	1,050	65	200
4-P/C-6	1,570	75	5,000
4-P/C-7	290	22	2,000
4-P/C-8	1,030	58	5,000
4-P/C-9	1,050	150	175
4-P/C-10	200	17	250
4-P/C-11	765	115	20

(1) Does not include weight of barium release cannisters at 100 lb each.

(2) Volume listed as launch configuration.

Table 4-12 (Page 4 of 6)

ESTIMATES OF INSTRUMENT CHARACTERISTICS

Research Cluster	Weight (Lbm)	Volume (Ft^3)	Average Power (Watts)
4-CR-1-10	35,000	4,000	10,000
4-PP-1	1,100	10	200
4-PP-2-1	100(1)	60	60
4-PP-2-2	1,000	20	100
4-PP-2-3	220	5	100
4-PP-3-1	100(1)	60	60
4-PP-3-2	220	5	100
4-PP-3-3	450	7	500
4-PP-4-1	100(1)	60	60
4-PP-4-2	1,000	20	100
4-PP-4-3	220	5	100
Communications and Navigation			
5-N-1	1,690	180	25
5-N-2	1,675	785	25
5-P-1	1,645	120	25
5-P-2	1,650	195	25
5-P-3	1,415	730	25
5-P-4	950	760	50
5-TF-1	2,415	315	800
5-TF-2	3,155	1,000	800
5-CS-1	1,645	820	350
5-CS-2	580	35	500
5-NS-1	430	23	50

(1) Does not include weight of barium release cannisters at 100 lb each.

Table 4-12 (Page 5 of 6)

ESTIMATES OF INSTRUMENT CHARACTERISTICS

Research Cluster	Weight (Lbm)	Volume (Ft^3)	Average Power (Watts)
Communications and Navigation (cont)			
5-NS-2	560	31	500
5-NS-3	565	810	50
5-NS-4	1,175	780	25
5-NS-5	940	745	25
5-NS-6	1,110	70	50
Earth Observations			
6-EP-1	3,110	120	1,300
6-EP-2	4,120	250	4,000
6-A/F-1	4,400	310	4,800
6-A/F-2	4,000	300	4,600
6-A/F-3	3,900	290	4,600
6-A/F-4	3,900	290	4,600
6-A/F-5	4,385	174	2,200
6-G/C-1	3,110	120	1,300
6-G-1	4,090	230	3,900
6-G-2	4,000	210	3,900
6-G-3	4,070	240	3,300
6-G-4	4,060	220	4,000
6-G-5	4,050	220	3,900
6-G-6	4,055	220	3,900
6-H-1	3,170	120	1,300
6-H-2	2,370	175	3,200
6-H-3	4,000	220	3,800
6-H-4	4,010	230	3,200
6-H-5	2,790	190	700
6-H-6	2,010	70	600

Table 4-12 (Page 6 of 6)

ESTIMATE OF INSTRUMENT CHARACTERISTICS

Research Cluster	Weight (Lbm)	Volume (Ft^3)	Average Power (Watts)
Earth Observations (Cont)			
6-H-7	4,000	200	3,800
6-O-1	2,255	80	700
6-O-2	3,350	145	800
6-O-3	2,184	81	700
6-O-4	1,910	150	3,100
6-O-5	2.240	170	3,000
6-O-6	3,395	140	1,500
6-O-7	1,900	82	700
6-M-1	1,475	35	600
6-M-2	830	11	500
6-M-3	30	20	65
6-M-4	350	100	200
6-M-5	970	21	500
6-M-6	1,945	65	600

Section 5

RESEARCH MISSION PLANNING REQUIREMENTS

In performing the analyses to develop future mission and spacecraft requirements, it is recognized that conceptual mission planning in toto encompasses many major considerations. Among them are not only technical and scientific objectives but also intangible (and rather unpredictable) political, economic-sociological, and budgetary factors.

This section has necessarily been limited to the technical and scientific areas only. Its main purpose is to give planning information, to describe analytical techniques to support the mission planner in assembling data from this study, and to demonstrate methods for defining potential space activities. By proper application of these methods and techniques, a rapid, preliminary evaluation of candidate mission concepts can be performed.

The objective of developing analytical methods is to obtain a means of exposing and eliminating those concepts that either are not feasible or may not be worthy of more detailed analysis. At the same time, concepts that prove of value may be given further attention in examining options or operational compromises that appear reasonable. This process is fundamental to conceptual mission planning, is iterative by its very nature, and tends to validate selected courses of action.

Mission and spacecraft planning as presented herein is dependent upon having available a set of clear, definitive, scientific and technological application objectives for the six space-oriented disciplines, namely Manned Space Flight Capability, Space Biology, Space Astronomy, Space Physics, Communications and Navigation, and Earth Observations. As these objectives were being developed in the course of completing the study's organized overview, they led to the definition of research information needs that were presented in the form of critical issues. By interpretation, the solutions to critical issue questions therefore become an expression of the information necessary to meet the scientific or technological objectives of the research. The most promising space activities are those configured to achieve a measurable information gain with the least investment of resources.

Each step in the process of defining critical space research requirements contributed to the final consolidation and grouping of the critical issues into 136 research clusters. It should be noted that these research clusters prescribe whole groupings of suggested space measurement activities rather than point experiment measurements. However, mission planning must ultimately deal with individual point measurements which, in summation, constitute the total program being proposed. Thus, each candidate mission becomes a step toward fulfilling the total data-gathering requirement.

The total of 136 research clusters comprises a data base of research that translates critical issues into manned space measurement activities for each of the six disciplines. In the information described in the preceding section and in Appendix C, a number of relevant descriptors are available to identify the particular crew requirements and the orbital, environmental, and spacecraft conditions under which the space experimentation is to be conducted.

The mission planning diagram, Figure 5-1, illustrates the many technical and operational considerations that collectively influence the development of definitive mission concepts. Each consideration, in turn, identifies a major decision point from which critical planning direction is obtained. Those aspects of space and manned operational requirements that are specifically applicable include instrumentation; measurement techniques; impact on spacecraft subsystems; support and logistics; and such functions as rendezvous and docking, extravehicular activities, maintenance and repair, and subsatellite retrieval. Each of these elements contributes to the determination of space experiment responsiveness in terms of critical information needs. It then remains to develop, and capitalize on, the commonalities and interrelationships among experiments within the constraints imposed by spacecraft operations and the operating environment.

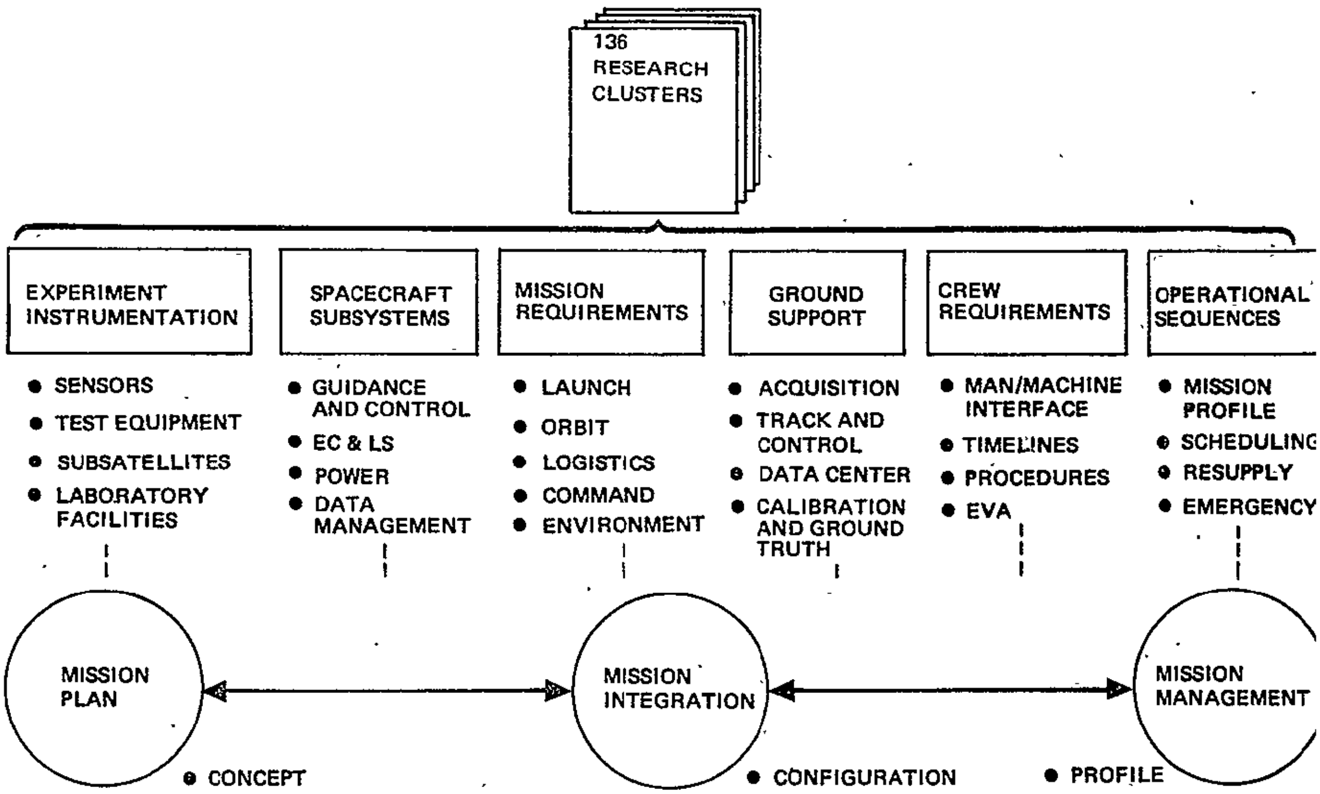


Figure 5-1. Mission and Spacecraft Planning

5.1 BACKGROUND

For this study, mission planning may be defined as the process of selecting, within imposed constraints, a set of space experiments and then seeking to balance many conflicting demands on resources in achieving mission objectives proposed for the experiment set. The process is iterative, and a balance can be accomplished only after many decision points have been reached and the impact of possible courses of action assessed. This process is the main topic of this section of the report. Its purpose is to emphasize the methods useful to a mission planner in dealing with decision analysis rather than offering specific solutions.

The approach presented, although admittedly not complete, appears promising and worthy of further refinement. It attempts to analytically treat space activities proposed by each of the research clusters, in terms of the space environment, spacecraft demands, and experiment instrumentation interfaces.

At the outset, however, certain provisions were established to limit the dimensions of the analysis task while still retaining a credible approach to broad mission planning. One NASA stipulation for the study was to exclude making any cost estimates for the proposed research activity. Another was to avoid any direct comparison with existing space research programs. Finally, as a basic ground rule, the technical requirements and the instruments and experimentation techniques contained in the experiment descriptions were accepted at face value. For example, no consideration was given to any nonavailability constraints imposed by future requirements for supporting technology development. The analysis steps taken assumed that all of the instrumentation was available as required by the research activities.

In view of the foregoing provisions taken in the context of research information developed earlier for this study, how may the nature and extent of the mission and manned spacecraft concepts be described? Referring to a simplified flow diagram, Figure 5-2, the character of broad mission planning is such that an iterative process is necessary to assure the inclusion of scientific and application program objectives into the mission definition. The eight points shown depict the principal areas of planning interest. An expansion of the iterative flow logic may be traced in more detail by referring to Figure 5-3. This figure summarizes the information interrelationships involved in mission planning. Each of the intersecting blocks identifies the nature of the information exchange between two of the principal subjects identified along the diagonal. The rows identify information <u>supplied</u> by the primary box in the row. Each of the columns identifies information <u>required</u> by the primary box it contains. The diagram is read clockwise in descending numerical order between any two primary boxes, at the intersecting row and column box.

In tracing Figure 5-3 at the Space Station Capabilities and Requirements (5.0) level, for example, along the row to the intersecting block with Crew Capabilities and Requirements (6.0), it is seen that two primary demands must be provided. The space station capabilities being considered should supply information for specifying both support and mission operations demands. These data are obtained from mission inputs identified in the four top blocks in the column above block

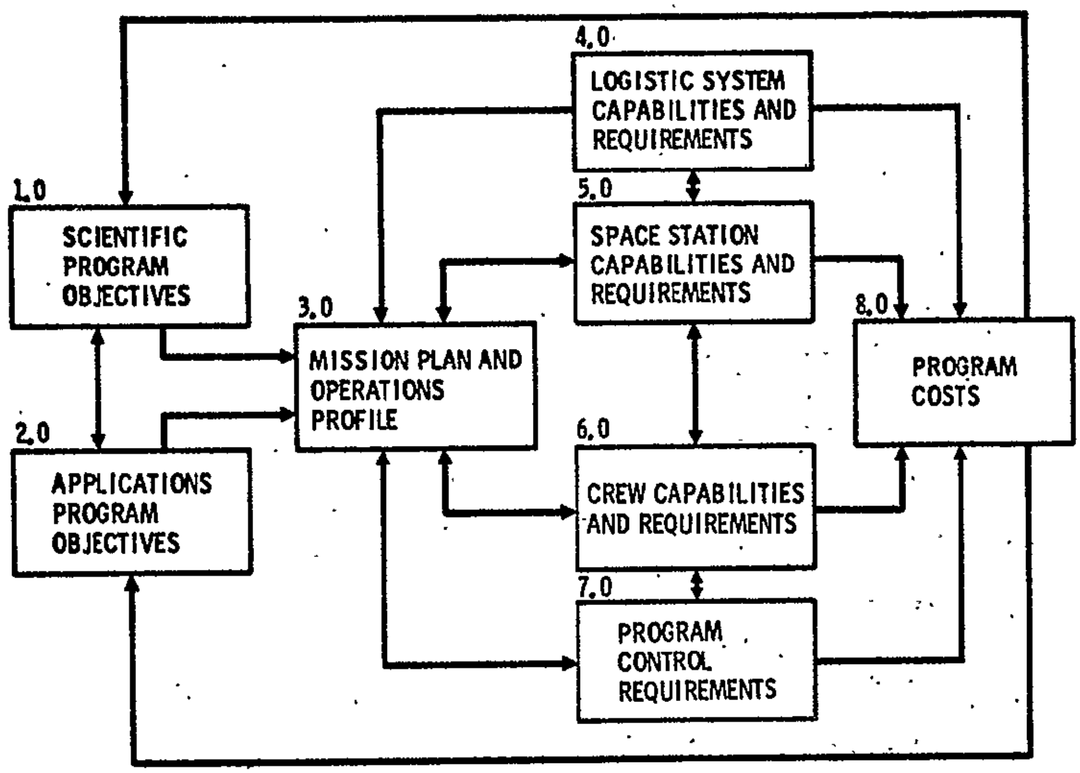


Figure 5-2. Top-Level Logic Flow—Mission Planning

1.0 SCIENTIFIC OBJECTIVES	• SCHEDULE OF MEASUREMENTS WHAT WHEN WHERE HOW	• ORBIT REQUIREMENTS • ENVIRONMENT REQUIREMENTS • SEQUENCE AND TIMING • CREW SKILL REQUIREMENTS • CREW TIME REQUIREMENTS REAL TIME DATA REQUIREMENTS • ON-LINE DECISION REQUIREMENTS • SUPPORT FACILITIES EQUIPMENT REQUIREMENTS	• PAYLOAD WEIGHT AND VOLUME REQUIREMENTS	VOLUME AND POWER REQUIREMENTS	• CREW SKILL REQUIREMENTS • CREW TIME REQUIREMENTS SCHEDULE REQUIREMENTS		
• SCHEDULE OF MEASUREMENTS WHAT WHEN WHERE HOW	2.0 APPLICATIONS OBJECTIVES	• ORBIT REQUIREMENTS • ENVIRONMENT REQUIREMENTS • SEQUENCE AND TIMING CREW SKILL REQUIREMENTS • CREW TIME REQUIREMENTS • REAL TIME DATA REQUIREMENTS • ON-LINE DECISION REQUIREMENTS • SUPPORT FACILITY EQUIPMENT REQUIREMENTS	• PAYLOAD WEIGHT AND VOLUME REQUIREMENTS	• VOLUME AND POWER REQUIREMENTS	• CREW SKILL REQUIREMENTS • CREW TIME REQUIREMENTS • SCHEDULE REQUIREMENTS		
• AVAILABLE ORBITS • MISSION SCHEDULE CONSTRAINTS	• AVAILABLE ORBITS • MISSION SCHEDULE CONSTRAINTS	3.0 MISSION PLAN AND OPERATIONS PROFILES	• DURATION NUMBER OF LAUNCHES PAYLOAD/ORBIT REQUIREMENTS SCHEDULE REQUIREMENTS	• DURATION/ORBIT RESUPPLY CYCLE • CREW ROTATION CYCLE • OPERATION REQUIREMENTS • MISSION/SUPPORT SCHEDULE	• CREW SKILLS AVAIL. CREW TIME LINE • OPERATIONS SCHEDULE	• ORBIT REQUIREMENTS • REAL TIME DATA REQUIREMENTS • ON LINE DECISION REQUIREMENTS • IMPACT OF PRIME FAILURE MODE	PROGRAM DURATION
• LAUNCH ENVIRONMENT • PAYLOAD/ORBIT ENVELOPE	• LAUNCH ENVIRONMENT • PAYLOAD/ORBIT ENVELOPE	• LOGISTIC SUPPORT PLAN • PAYLOAD/ORBIT SELECTION	4.0 LOGISTIC SYSTEM CAPABILITIES AND REQUIREMENTS	• PAYLOAD WEIGHT AND VOLUME CONSTRAINT BY ORBIT • LAUNCH RATE • UNSCHEDULED LAUNCH RESPONSE CAPABILITY	• LAUNCH SCHEDULE • PAYLOAD DELIVERY SCHEDULE	• LAUNCH ON TIME PROBABILITY • LAUNCH VEHICLE RELIABILITY	• LAUNCH VEHICLES • LAUNCH RATE UNSCHEDULED LAUNCH PROVISIONS
• AVAILABLE WEIGHT, VOLUME, POWER • AVAILABLE CREW TIME • AVAILABLE SUPPLIES AND INSTRUMENTATION • CONTROL REQUIREMENTS AND SCHEDULE OPTIONS	• AVAILABLE WEIGHT, VOLUME POWER • AVAILABLE CREW TIME • AVAILABLE SUPPLIES AND INSTRUMENTATION • CONTROL REQUIREMENTS AND SCHEDULE OPTIONS	• LIFETIME • PROBABILITY OF SURVIVAL • EMERGENCY RESPONSE CAPABILITY	• CONSUMPTION RATE • STORAGE CAPACITY • FAILURE RATES • SPARES INVENTORY	5.0 SPACE STATION CAPABILITIES AND REQUIREMENTS	• SUPPORT OPERATIONS DEMANDS • MISSION OPERATIONS DEMANDS	• NUMBER IN CREW • CONTROL SUPPORT (INFORMATION PROCESSING) CAPABILITIES	• DEPLOYMENT REQUIREMENTS • SUPPORT REQUIREMENTS
• AVAILABLE CREW SKILLS	• AVAILABLE CREW SKILLS	• PERFORMANCE PROFILE VS TOUR OF DUTY	• TOUR OF DUTY • NUMBER IN CREW • NUMBER OF CREW ROTATED AT A TIME	• AVAILABLE CREW TIME, SKILLS • CREW COMFORT LEVEL • EMERGENCY PROVISIONS REQUIRED	6.0 CREW CAPABILITIES AND REQUIREMENTS	• DEGREE OF CREW AUTONOMY	• NUMBER IN CREW • TOUR OF DUTY • SKILL MIX
• CONTROL CENTER LOCATIONS • CONTROL RESPONSIBILITY	• CONTROL CENTER LOCATIONS • CONTROL RESPONSIBILITY	• PRIMARY/SECONDARY CONTROL RESPONSIBILITIES • CONDITIONS OF TRANSFER OF RESPONSIBILITY FOR CONTROL	• GROUND ASCENT, ORBIT, DESCENT LANDING CONTROL RESPONSIBILITIES	• INFORMATION/DATA PROCESSING REQUIREMENTS	COMMAND/CONTROL RESPONSIBILITIES	7.0 PROGRAM CONTROL REQUIREMENTS	• INFORMATION NETWORK REQUIREMENTS
• COST OF PROGRAM ELEMENTS • SENSITIVITY OF COST TO ELEMENT CHANGES	• COST OF PROGRAM ELEMENTS • SENSITIVITY OF COST TO ELEMENT CHANGES	• INTEGRATED COST PROFILE • HIGH-COST ELEMENTS AND THEIR DEMAND PROFILES	• COST OF LAUNCH SYSTEM • SENSITIVITY TO LAUNCH RATE	• COST OF SUBSYSTEMS COST OF OPERATIONS SENSITIVITY OF COSTS TO CHANGE	COST OF TRAINING SUPPORTING CREW MEMBERS	COST OF CONTROL SYSTEM	8.0 PROGRAM COSTS

Figure 5-3. Requirements for Mission Planning.

5.0; namely the volume and power requirements, duration and orbit, resupply cycle, crew rotation cycle, operation requirements, mission and support schedule payload weight and volume, launch rate, and unscheduled launch response. As a result of analysis of these parametric variables, the crew requirements data would forecast a crew mix in terms of available crew time and skill levels neede and treat the subjects of crew comfort and emergency provisions to complete the planned mission. This development of crew considerations would also be adjusted in response to any changes in the supplied information.

With the frame of reference portrayed by these two figures, an important goal of the mission planner is to select sets of activities that provide the most effective return in achieving the selected objectives. When a mission plan comprises more than one research discipline, a multidimensional set of mission, spacecraft, and instrument interface requirements must be developed, and the options of implementations must be evaluated. By way of illustration, Mission Plan and Operations Profile (3.0) shown on the flow diagram can be broken down into a subset of planning activities. These are given in Figure 5-4, and form the basis from which the mission analysis was accomplished for this study.

In compiling information on mission requirements, it was recognized that space measurement activities could be accommodated by at least one of four types of orbiting space vehicles: (1) a Space Station, (2) Experiment Modules attached to a Space Research Facility, and (3) Free-Flying Experiment Modules, and (4) the Space Shuttle. The basic distinctions for conceptual planning follow these lines:

A. Integral experiments and general-purpose laboratories are generally configured within a Space Station. Selected apparatus or specimens may be brought into orbit as cargo on a Space Logistics Shuttle and transferred to the station.

B. Attached experiment modules are self-contained extensions of the Space Station, which are configured to provide additional working space and special equipment. Operationally, these modules are docked and functionally integrated with the Space Station but are brought into space independently.

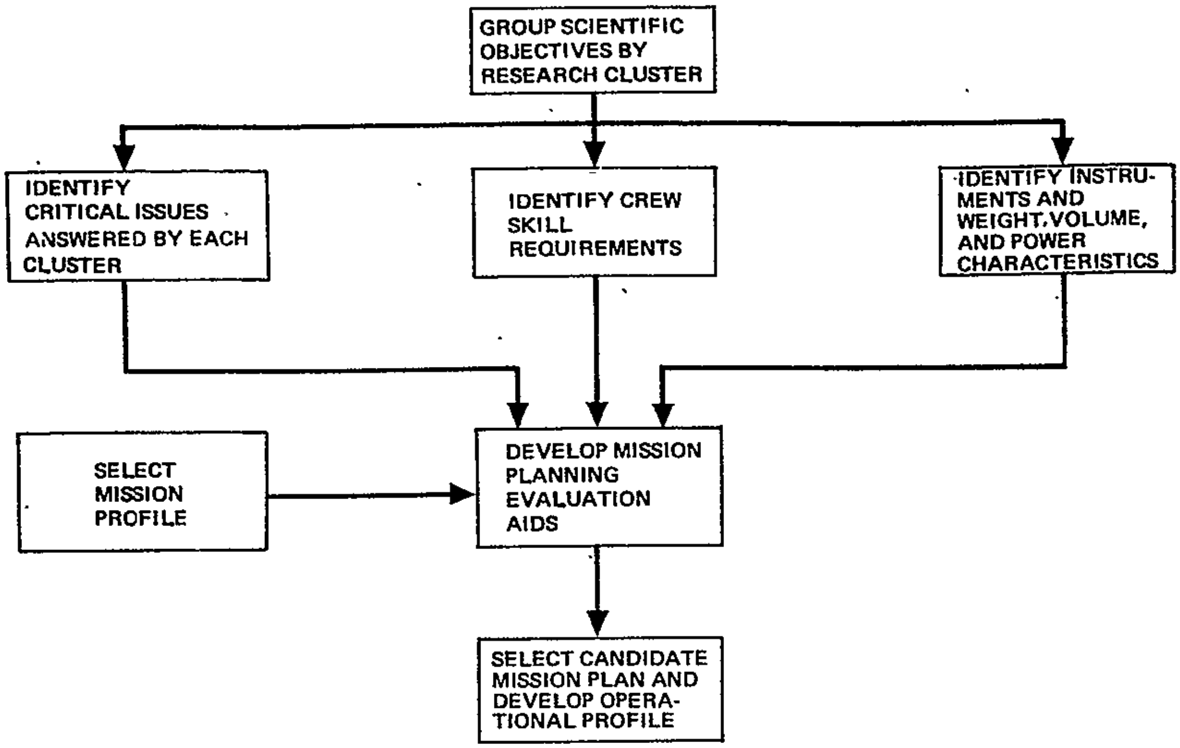


Figure 5-4. Flow Diagram—Mission Planand Operational Profile Development

C. Free-flying modules contain experiments that, by their nature, must be decoupled and isolated from Space Station accelerations or contamination, or are required to operate in orbits independent of the Space Station's orbit.

D. Shuttle Experiments are characteristically attended by a small crew, are of short term nature (5-7 days), and limited in terms of power, volume or data management. Experiments would probably be modular and less complex than free-flying modules, but permit adjustments of orbital planes and altitudes.

To illustrate the conceptual considerations stated above, the ability of four familiar space systems to accommodate the research clusters in each of the six scientific disciplines has been evaluated. These candidates include the use of an advanced Skylab. The characteristics of each system assumed for this analysis are presented in Table 5-1. Criteria used to determine whether a system could or could not accommodate a specific research cluster are summarized in Table 5-2. The results of this evaluation are depicted in Figure 5-5. The percentage of research clusters that could be accommodated on an individual basis has been presented for each discipline. Some of the evaluation decisions as to the feasibility of a system's accommodating a particular cluster may be argumentative; however, the overall set is believed to be representative for the system characteristics shown.

It is obvious that long-term missions are better suited to space stations than to the other vehicles, particularly those dependent upon man-oriented experiments. MSFC, Space Biology, and Space Physics are cases in point. The more automated experiments of Earth Observations and of Communications and Navigation are equally applicable to all platforms, although the longer-term requirements favor the Space Station concepts. In the case of Astronomy, the unattached module is clearly the best choice, primarily because of the disturbing accelerations created by men being aboard the spacecraft. It should be noted that 20 percent of the astronomy research, which deals with low-frequency radio astronomy in synchronous orbit, could not be accommodated by any of the systems postulated in Table 5-1.

Table 5-1

SPACE VEHICLE CONCEPTS

Space Station	Skylab	Module	Shuttle
Multimanned Laboratory	3-Man Crew	Unmanned-Remotely Controlled	Manned-Limited Crew
Attached Modules and Dock for Free Flyers	Attached Module(ATM)	Self-Controlled Stabilization and Attitude	Volume Limit 14 x 58 ft Payload
Long Orbit Life (yr)	1- to 2-year Orbit Life - Series of 56-day Missions	Limited Orbit Life	7- to 30-Day Mission
25-kw Prime Power	12-kw Prime Power	5-kw Prime Power Maximum	5-kw Prime Power
55-Degree Inclination	55-Degree Inclination		Variable Inclination: 28 to 100 degrees
200 to 300-nmi Altitude	235-nmi Altitude	Logistics from Space Station*	Altitude: 100 to 400 nmi
Pointing accuracy: Station plus Sensor Platform > 10 sec	Pointing Accuracy: Station plus ATM Platform 1 min	Pointing Accuracy: Module plus Sensor Platform > 0.02 sec	Coarse Pointing

*Limits inclination and altitude to the vicinity of the Space Station orbit.

Table 5-2

ACCOMMODATION OF RESEARCH CLUSTERS

Evaluation Criteria
Active Crew Participation During Data Run
Length of Data Run Greater than 1 Month
Demands Integrated and Sequential Measurements
Human Centrifuge Required
Precision Stability or Pointing Required
Geo-Synchronous Orbit Required
Exceeds 5-kw Prime Power
Controllable Low-Level Gravitation Field
Polar Orbit Required
Space Station Specified in Experiment

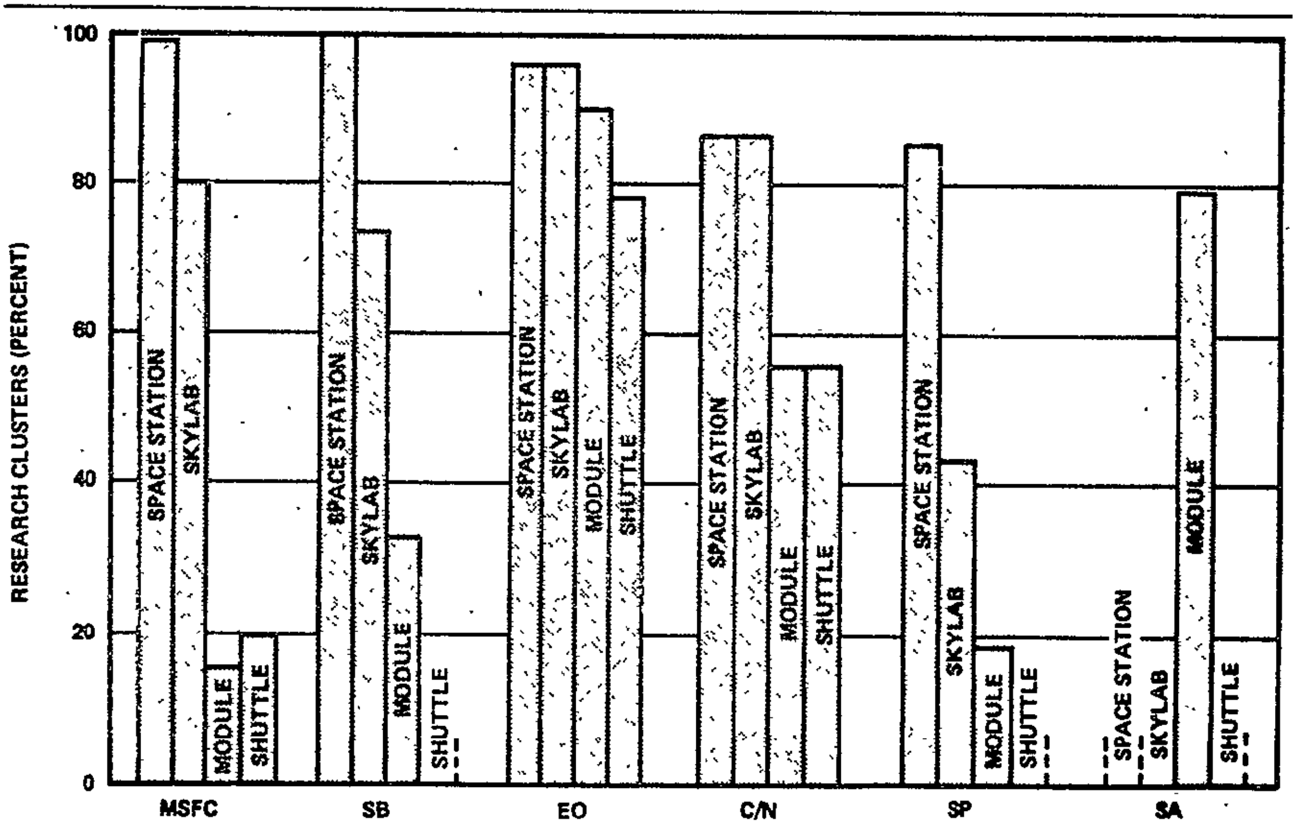


Figure 5-5. Evaluation of System Options.

In treating the broad area of space research presented in this report, each of the above concepts offers certain operational advantages and disadvantages in terms of research flexibility and constraincs. To provide information that can be used in examining these and other feasible implementation concepts, certain mission planning factors must be considered. The remainder of this section will address these factors.

The material for this section of the report was prepared in three parts. The first part addresses the routine problem of grouping the research cluster description statistics into meaningful segregations by mission commonalities. In the second part, important and useful parametric mission and spacecraft guideline information and supporting diagrams and graphs are presented to illustrate some of the more general planning factors needed. The third part deals with the more difficult problem of mission analysis. The process for developing a typical mission example, derived from selected operational criteria, is used to highlight the applicable analysis techniques and strategies relevant to selecting proper courses of action.

The general procedures developed for mission planning are briefly summarized as follows: data described in the experiment descriptions were first collected and compiled into appropriate composite groups exhibiting selected-orbit or operational characteristics. The more straightforward orbit elements examined were those dealing with mission altitude, inclination, and stabilization or orientation of the spacecraft. An initial statistical compilation categorized each of these common demands into like groups. Appropriate scalings were selected to establish the boundary conditions of the cells of common characteristics. These data were presented in Section 4, Subsection 4.1, Orbit Parameters.

The research clusters were then surveyed for any data relevant to spacecraft configuration planning. An instrumentation matrix was assembled for research groups in each discipline, and a master list of common instruments was extracted from the data. Space vehicle subsystems were then considered to determine any spacecraft sizing and integration impact where unique experiment requirements were identified. The data management system is treated with particular interest. Finally, the important parameters of research cluster weight, volume, and power have been estimated for the basic and support apparatus specified for each experiment group description. These estimates are found in Section 4, Subsection 4.5, Summary of Research Cluster Weight, Volume, and Power Requirements.

Any operational or unique design characteristics related to mission implementation or to execution of the various measurement processes were also considered. Crew-skill requirements and activities were likewise assessed to identify and categorize the measurements where EVA must be performed or where man is to be the primary object of the test. Unique research activities requiring remoted operations for completed experimentation in terms of additional space vehicles (i.e., modules or subsatellites) were also identified.

To illustrate a practical application of the analysis methodology to a mission problem, basic Earth Observations instrumentation strategies were developed for a planning example. One strategy involves an assessment of the number of times a particular instrument is used by the research clusters selected to meet mission operational criteria. A second strategy examined the largest number of critical issues to be answered with the least number of instruments. For each strategy employed, an ordering of instruments was obtained and the results were plotted.

Another step taken in the analytical process was to determine sensitivity to changes in the research clusters selected for a mission. A technique was devised to gain insight into the impact of any changes to be expected by removing or adding to the research instrumentation. A selection process is shown (Subsection 5.7.3), which helps the planner identify research clusters having relatively low information-gain for large investments in crew, or in spacecraft volume, weight, or power.

The mission analysis steps summarized above are explained in greater detail in the following paragraphs.

5.2 FACTORS IN MISSION ANALYSIS AND COMMONALITY GROUPING

The various factors relevant to defining missions are not only numerous but extremely complex in terms of their influences on one another. Broad conceptual planning is indeed possible, even though desirable details may be either unknown, undeveloped, or omitted from the available research cluster descriptions. Any meaningful analysis, therefore, will demand careful judgement and sharp intuition on the part of the planner. As stated previously, the approach taken begins with the preparation of statistical inputs for development of effective, compatible groupings of experiments. Some of the important characteristics sought in conducting commonality groupings across the six research disciplines include:

A. Mission orbit and space environment

B. Space vehicle operational and design constraints.

C. Experiment instrument and facility requirements.

D. Data acquisition and information management demands.

E. Special resource and support demands, including ground operations.

While the experiment requirements set forth the basic criteria for performing a mission, the various elements that make up an integrated payload may not be singularly important in themselves. They may, however, have significant effect or influence on many mission planning parameters. To illustrate, the space mission and manned orbiting vehicle considerations will include many items that could be hazardous to crew safety, characterized either by radiation, toxicity, or inflammability. These subjects are not usually treated in any detail during the early stages of developing a mission plan.

5.2.1 Instrument Matrix

In the development of planning methodology, detailed matrices were prepared to indicate the main instruments, apparatus, and tools, and in some cases, the general facility equipment defined for the research clusters. The product of this effort, presented in Subsection 5.6, forms the basis for conceptual space-facility configuration development. The matrix of instruments cited serves as an important tool in the analysis process, where mission strategies are being developed to highlight compatible research areas. This analysis is further explained in Subsection 5.7, Mission Planning Example, when instrument requirements are correlated with the research critical issues.

5.2.2 Matrix of Mission Selection Parameters

Following the preparation of instrument summaries, several of the important mission selection parameters were identified. The main purpose was to review and classify each research cluster and to select those having basic compatibilities from the total. A simple matrix was developed to expedite this process, as illustrated in Figure 5-6. The prime mission-planning parameters chosen for the screening procedure are:

A. Orbit:
   1. Altitude (low $H < 300$ nmi; medium $300 < H < 1000$ nmi; and high $H > 1000$ nmi).
   2. Inclination (low, $< 30°$; medium, $30° < i < 60°$; and high, $i > 60°$
B. Spacecraft Pointing:
   1. Orientation (Earth,space).
   2. Accuracy (low, > 30 min; medium, > 10 sec; and high < 10 sec).
C. Spacecraft Demand:
   1. Volume (>100 ft^3).
   2. Power (>3,500 w).
   3. Weight (>1,000 lbm).
D. Environment:
   1. Separate or free flying.
   2. Acceleration sensitive.
   3. Cryogenics.
   4. Artificial-g.
   5. Atmosphere control.
   6. High temperature >1,000°F
E. Crew Requirement:
   1. EVA
   2. Crew as subject.
F. Special Requirements:
   1. Structure.

RESEARCH CLUSTER \ MISSION PLANNING PARAMETER	ORBIT – ALTITUDE – LOW (H < 300 NMI)	ORBIT – ALTITUDE – MED (300 < H < 1,000 NMI)	ORBIT – ALTITUDE – HIGH (H > 1,000 NMI)	ORBIT – INCLINATION – LOW (i < 30°)	ORBIT – INCLINATION – MED (30° < i < 60°)	ORBIT – INCLINATION – HIGH (i > 60°)	ORBIT – SPECIAL ORBIT RQMTS	SPACECRAFT POINTING – ORIENTN – TOWARD EARTH	SPACECRAFT POINTING – ORIENTN – TOWARD SPACE	SPACECRAFT POINTING – ACCURACY – HIGH (< 10 SEC)	SPACECRAFT POINTING – ACCURACY – MED (10 SEC - 30 NMI)	SPACECRAFT POINTING – ACCURACY – LOW (> 30 MIN)	SPACECRAFT DEMAND – VOLUME – HIGH (> 100 FT³)	SPACECRAFT DEMAND – POWER (AVG) – HIGH (> 3500 W)	SPACECRAFT DEMAND – WEIGHT – HIGH (> 1000 LBM)
I-BM-4														
I-BM-5														
I-BM-6														
I-BM-7														
I-BM-8														
I-BM-10														
I-BM-12														
I-BM-13														
I-BM-14														
I-BM-15														

RESEARCH CLUSTER \ MISSION PLANNING PARAMETER	ENVIRONMENT REQUIREMENTS – SEPARATION FREE FLYING REQ	ENVIRONMENT REQUIREMENTS – ACCELERATION SENSITIVE	ENVIRONMENT REQUIREMENTS – CRYOGENICS REQUIRED	ENVIRONMENT REQUIREMENTS – ACCELERATION (ARTIFICIAL GRAVITY) REQUIRED	ENVIRONMENT REQUIREMENTS – ATMOSPHERE CONTROL	ENVIRONMENT REQUIREMENTS – HIGH TEMPERATURE	CREW RQMT – EVA REQUIRED	CREW RQMT – CREW AS SUBJECT	SPECIAL REQUIREMENTS – STRUCTURE	SPECIAL REQUIREMENTS – SHIELDING	SPECIAL REQUIREMENTS – HUMAN CENTRIFUGE	SPECIAL REQUIREMENTS – ANIMALS	SPECIAL REQUIREMENTS – REAL TIME DATA	SPECIAL REQUIREMENTS – PHOTO DEVELOPMENT	SPECIAL REQUIREMENTS – EFFLUENT SENSITIVE	SPECIAL REQUIREMENTS – EMI SENSITIVE	SPECIAL REQUIREMENTS – THERMAL CONTROL	SPECIAL REQUIREMENTS – COOLING REQUIRED		
I-BM-4								●										●		
I-BM-5												●	●					●		
I-BM-6								●										●		
I-BM-7								●					●	●						
I-BM-8								●										●		
I-BM-10								●										●		
I-BM-12												●	●				●	●		
I-BM-13								●										●		
I-BM-14								●										●		
I-BM-15		●						●			●							●		

Figure 5-6. Mission Planning Worksheet

2. Shielding
3. Human centrifuge.
4. Animals.
5. Real-time data.
6. Photo development.
7. Effluent sensitive.
8. Electromagnetic interference (EMI) sensitive.
9. Thermal control.
10. Cooling required.

5.2.2.1 Special Requirements

The screening matrix used for mission candidate selection (Figure 5-6) lists ten categories identified as special requirements. These ten categories are intended to bring attention to aspects of the research clusters that should be considered during mission planning. Some of the requirements are self-evident, and others need further explanation. This section briefly discusses those that might be unclear, as follows:

A. Structure. Research clusters identified in the structure column require some special structural accommodation. The requirement might include internal spacecraft structure; unusual mounting, size, or other details; or accommodations inside the spacecraft.

B. Shielding. The shielding column identifies the research clusters that have special radiation shielding requirements. This need might arise from either the sensitivity of some experiment and its radiation protection requirements, or from the presence of a source as part of an experiment and the need for protecting the rest of the spacecraft.

C. Human Centrifuge. This requirement has a large impact on the spacecraft. If a research cluster includes the need for a human centrifuge, the planner must recognize the power and weight penalties.

D. Animals. A research cluster that calls for animals entails special volume, weight, and resupply consequences. In general, animals refer to canines and primates. However, each research cluster identified in this column must be reviewed to define the exact nature of the requirement.

E. Realtime Data. This data requirement identified research clusters that will impact the communications system by requiring the transmission of realtime data. Consequences might include a power demand, number of operation times and their duration, and data-processing capabilities.

F. Photo Development. This column identifies research clusters that might require onboard darkroom facilities and supplies.

G. Effluent-Sensitive. The research clusters identified by this column include one or more experiments that require protection from effluents that might be present from other experiments or spacecraft operations. The impact of the effluent emissions on those sensors mounted on the spacecraft exterior will dictate the amount of protection required.

H. EMI-Sensitive. These research clusters require special protection from electromagnetic interference.

I. Thermal Control. This parameter identifies research clusters that require special thermal control for special heat rejection or protection. Active or passive methods can be decided upon by reviewing the requirement and the demand level.

J. Cooling Required. This parameter identifies research clusters that require active cooling, especially cryogenic cooling.

Although the above were selected as being indicative of the planning parameters and therefore represent important initial demands leading to broadly defined missions, they are not to be construed as the totality of requirements. A more, detailed classification process at this stage is not advisable, however, and the approach avoids an unwarranted generation of details. It remains for the mission planner to select and develop a representative set tailored to reflect sensitive or key areas of importance. It is evident from the mission example developed later that interesting conclusions may be drawn from the overall classification accomplished, without having very precise information available for analysis. The resultant summary matrix is found in Subsection 5.7.1.

5.3 PLANNING GUIDELINES FOR CANDIDATE MISSIONS

A set of parametric charts and curves has been prepared to assist the space mission planner in the early phases of his task. These data relate the demands of experiment requirements and sensor performance to spacecraft characteristics. The data are not intended to be all encompassing, but the set should provide sufficient information for the mission planner to (1) make a gross estimate of some of the orbit parameters and spacecraft characteristics that would satisfy a particular set of experiment requirements; (2) broadly determine the impact of an experiment on orbit and spacecraft requirements; and (3) assess the responsiveness of an existing, or predetermined, mission and spacecraft design to general experiment requirements. Additional curves and graphs relating to space planning may be found in Section 3, Subsection 3.1.1.1 of this report.

Parametric information pertaining to the earth-viewing orbit considerations, space environment, and general spacecraft characteristics are discussed in the paragraphs that follow. This material is followed, in turn, by Subsection 5.4, dealing with the impact of crew capabilities on mission planning, and Subsection 5.5 which treats the area of data management systems. All of these subjects collectively constitute the basic planning reference material needed to propose and evaluate mission candidates.

5.3.1 Earth-Viewing Orbit Parameters

The dependence of sensor performance on orbit parameters is present in most of the disciplines considered in this study (Earth Observations, Space Physics, Space Astronomy, and Communications and Navigation). Since most of the orbit requirements come from the Earth Observations discipline and treat the subject in a comprehensive manner rather than piecemeal across several disciplines, only information dealing more directly with this discipline has been included. The sensor dependency discussed in this section applies to both image quality and visibility of selected ground sites.

An extremely important factor in both scheduling and evaluating experiment performance is the elapsed time that a particular target or truth site is visible from orbit. In Figures 5-7 and 5-8, the average visibility time (minutes per day) of a point target from a circular orbit is shown as a function of the orbit's characteristics (altitude and inclination), sensor-oriented geometry (satellite look-angle and elevation angle at the target), and target location (latitude). In the first illustration (Figure 5-7) the surface distance of the ground site from the subsatellite track (item d) has been plotted as a function of satellite look-angle (angle between the local vertical and the line-of-site from the satellite to the ground site) for a range of low Earth-orbit altitudes. Lines of constant elevation angle (the angle between the local horizontal and the target-to-spacecraft line-of-site measured at the target) are also shown in this figure. The second figure (Figure 5-8) relates the target-oriented geometry to visibility through a carpet plot that shows average viewing time versus allowable target distance from the ground trace and target latitude for typical values of the orbit inclination. Assumptions made

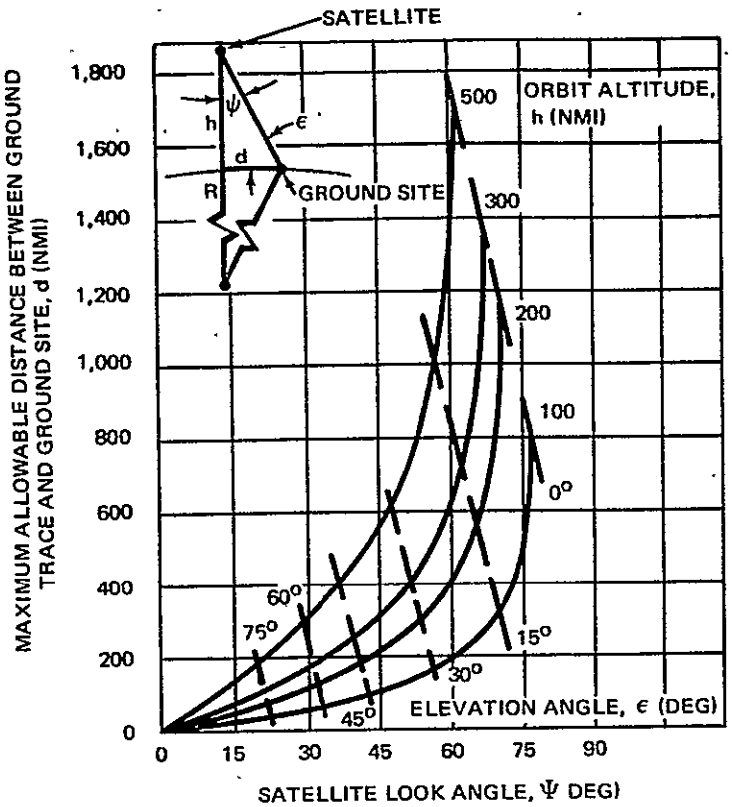


Figure 5-7. Ground Observation Geometry

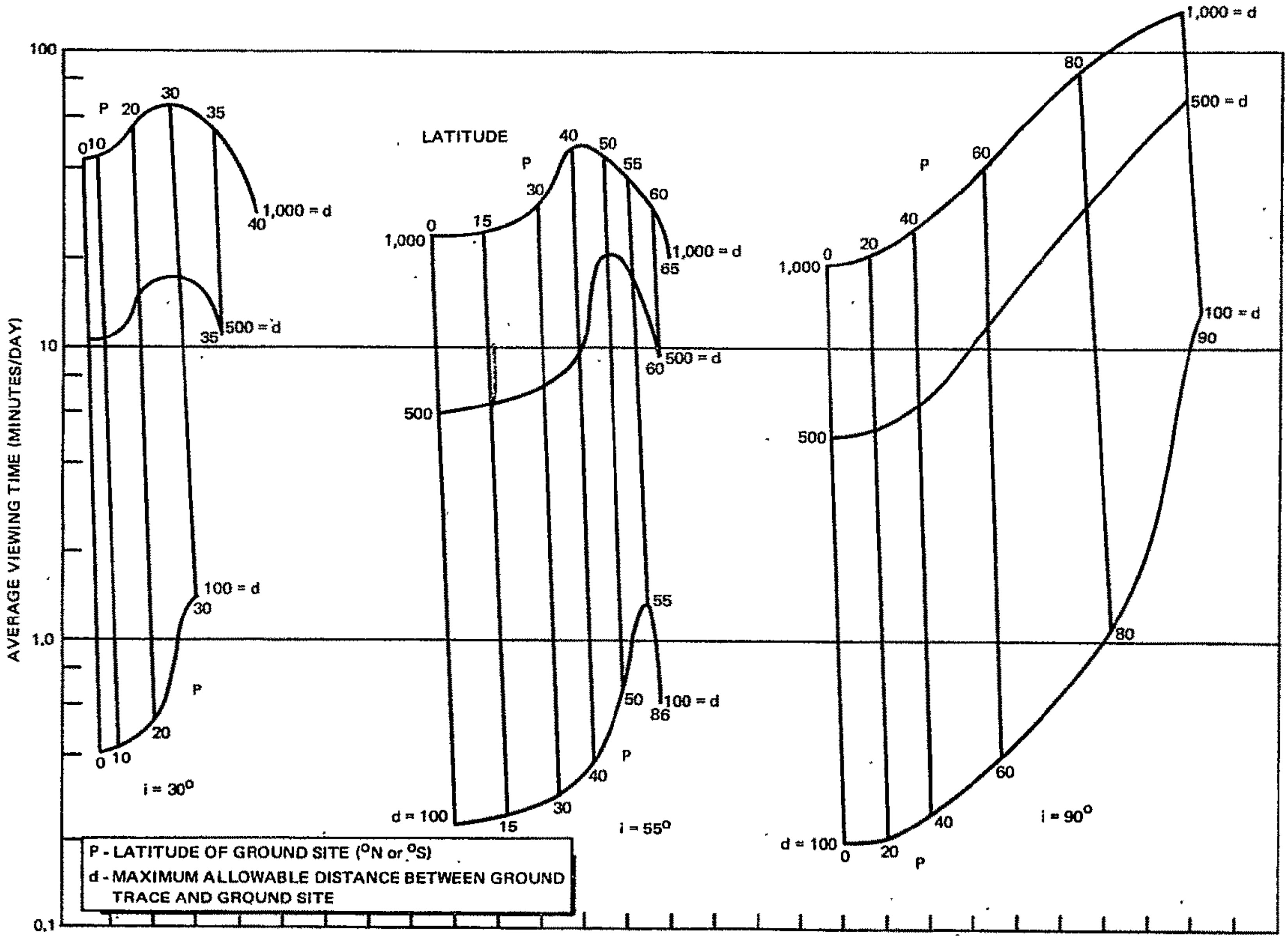


Figure 5-8. Ground Site Visibility—Inclination Cases 30°, 55° and 90°

in generating Figure 5-8 were: 1) ascending node location does not repeat, and 2) the target is visible anywhere within the circle defined by the sub-satellite point as center, and the distance d as surface radius. To illustrate the use of these figures, assume that a sensor has a gimbal angle capability of 45 degrees, that a target is located at 30-degree latitude, and that the spacecraft containing this sensor has an orbit with a 200-nmi altitude and a 55-degree inclination. From Figure 5-7, a 45-degree look angle and a 200-nmi altitude define a cross track distance of 320 nmi. At an inclination of 55 degrees, a target latitude of 30 degrees, and a "d" distance of 320 nmi (interpolated logarithmically), an average viewing time of 3.5 min per day is found from Figure 5-8.

The data presented in Figure 5-8 assumed a nonrepeating, ascending-node location. Substantial increases in viewing time for a fixed ground target can be obtained if the orbit altitude and inclination are selected and maintained to provide a subsynchronous orbit; that is, one that periodically repeats its ground trace. The locus of points, for several ground-trace repetition cycles, is shown on an altitude-inclination chart, Figure 5-9. (These repetition cycles are shown in terms of draconic days - the period required for the Earth to make one complete revolution with respect to the orbit plane, rather than solar days.) Unfortunately, disadvantages are also associated with subsynchronous orbits, in particular the lack of a complete mapping capability for sensors with relatively small fields of view and limited capability for gimballing. A compromise between repeatability and complete coverage is often desirable.

Figure 5-10 shows a variety of subsynchronous orbits with relatively long repetition cycles. Since the maximum distance between ground traces is inversely proportional to the repetition cycle, longer cycles mean shorter distances between adjacent traces and therefore better coverage. (For low Earth orbits, a 1-day subsynchronous orbit at 55-degree inclination, the maximum distance between traces is approximately 1000 nmi, as opposed to a 5-day subsynchronous orbit with a maximum separation distance between tracks of 200 nmi). The pyramiding of a number of suitable orbits, as repetition cycle increases, is shown in the figure. When scaled to the proper inclination, these data fill

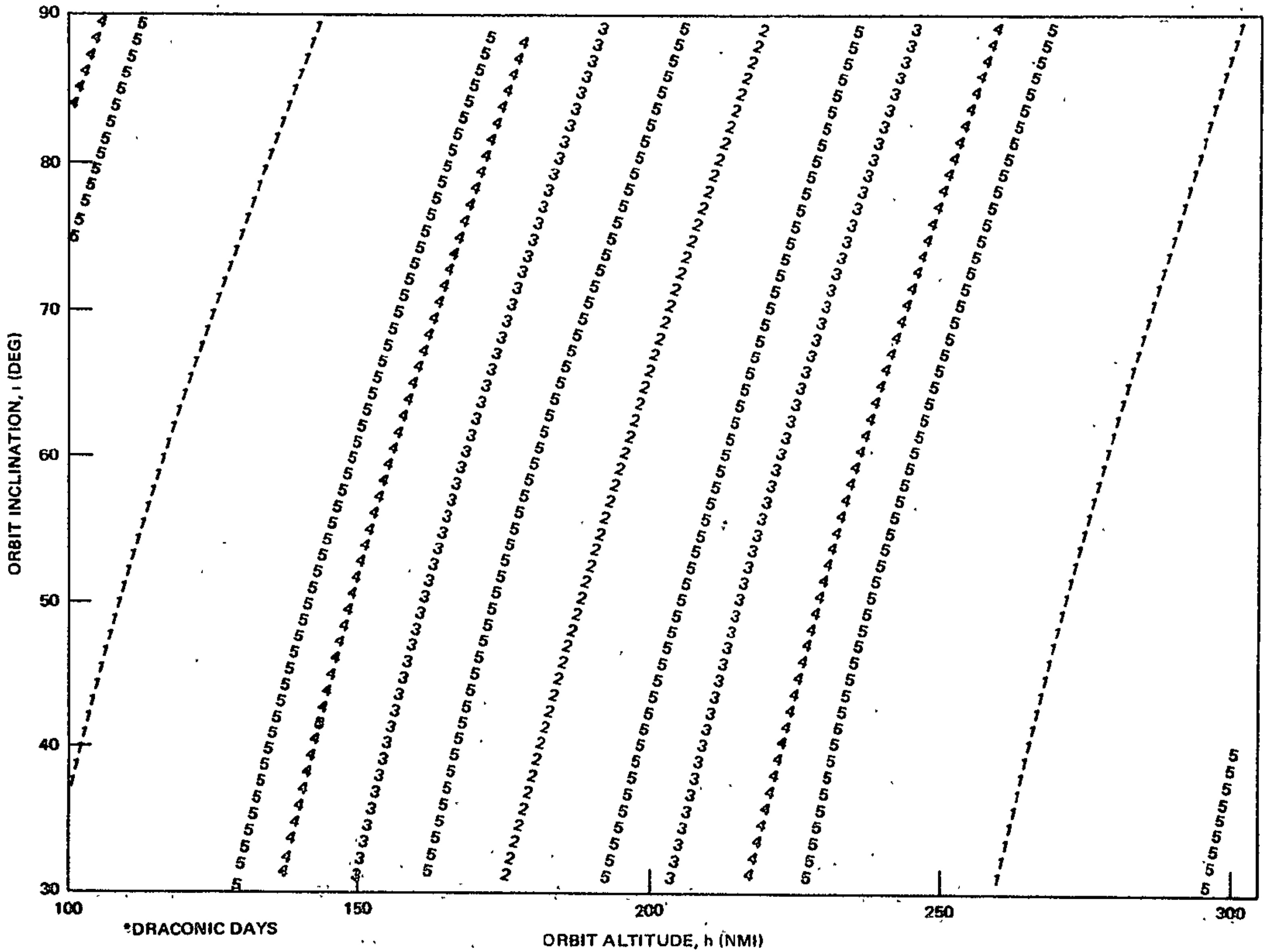
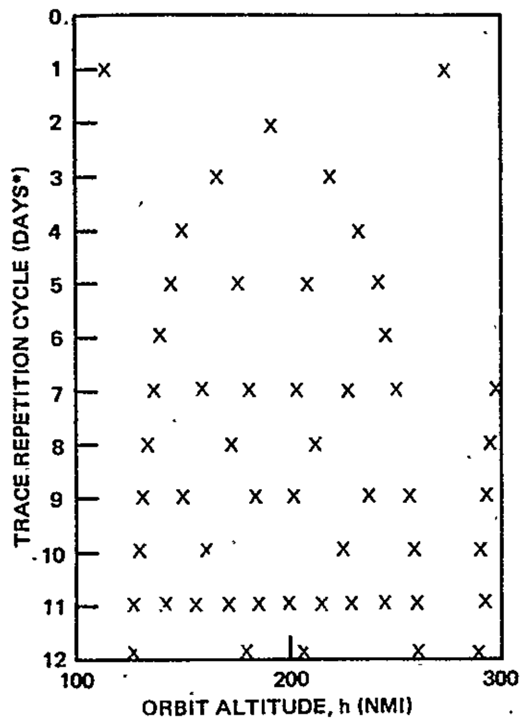


Figure 5-9. Repetitive Orbits—Number of Days* Before Retrace

the gaps in Figure 5-10. (This technique should not be extended indefinitely as it is based on a truncated Earth potential field model, and the resultant errors invalidate long-term repetition cycle predictions.)



*NODICAL DAYS

Figure 5-10. Repetitive Orbits Case i = 55°

One important consideration of Earth viewing, particularly photography in the visible spectrum, is the sun angle along the ground trace. The viewing time with the sun angle greater than a specified value is plotted in Figure 5-11 as a function of sun angle and β angle. (The sketch defines both angles.) It is obvious that sun angle constraints can seriously limit the time during which useful data can be gathered.

Possibly the most difficult task in the scheduling of ground observations is the prediction of cloud cover over a particular ground site. This is usually approached statistically by first analyzing the cloud cover data for the site and then estimating the probability of the site being visible when the spacecraft is overhead. Figure 5-12 shows the predicted visibility of the Purdue Farms truth-site as a function of month of the year and time of day. World-wide cloud cover statistics have been gathered and incorporated into a computer program that can rapidly search and manipulate the data to furnish visibility predictions as a function of geographical region, month of the year, and the time of day. Some Earth-viewing sensors, such as microwave scanners, are not hindered by cloud cover, but more sensors find it opaque. To provide guaranteed coverage of a particular site, several overflights may have to be scheduled. Even this may not be sufficient. For example, during the winter months in the Seattle, Washington area, the probability of a specified ground site being visible is less than 30 percent per pass.

The preceding six figures have dealt with the geometry between spacecraft and ground site, and with limitations on visibility. The three following figures focus on the sensor hardware and its interaction with orbit and the spacecraft. A nomograph, Figure 5-13, links ground resolution to sensor image resolution through orbit altitude and sensor focal length. Ground resolution is plotted versus angular resolution for representative spacecraft altitudes. (For comparison, several altitudes typical of aircraft operations have been included.) Angular resolution is then plotted as a function of system resolution for various sensor focal lengths in the upper half of the figure. Also shown are the diffraction limited aperture diameters. For a given sensor and film or vidicon resolution capability and a given altitude, the ground resolution can be found from this figure. Similarly, with a given ground resolution, film resolution, and altitude, the required sensor characteristics can easily be established.

Figure 5-14 is a diagram that indicates the number of pictures and the weight of film required to map a given area. These data are shown in nomograph form. Reading from the bottom left, the surface area to be mapped and the ground

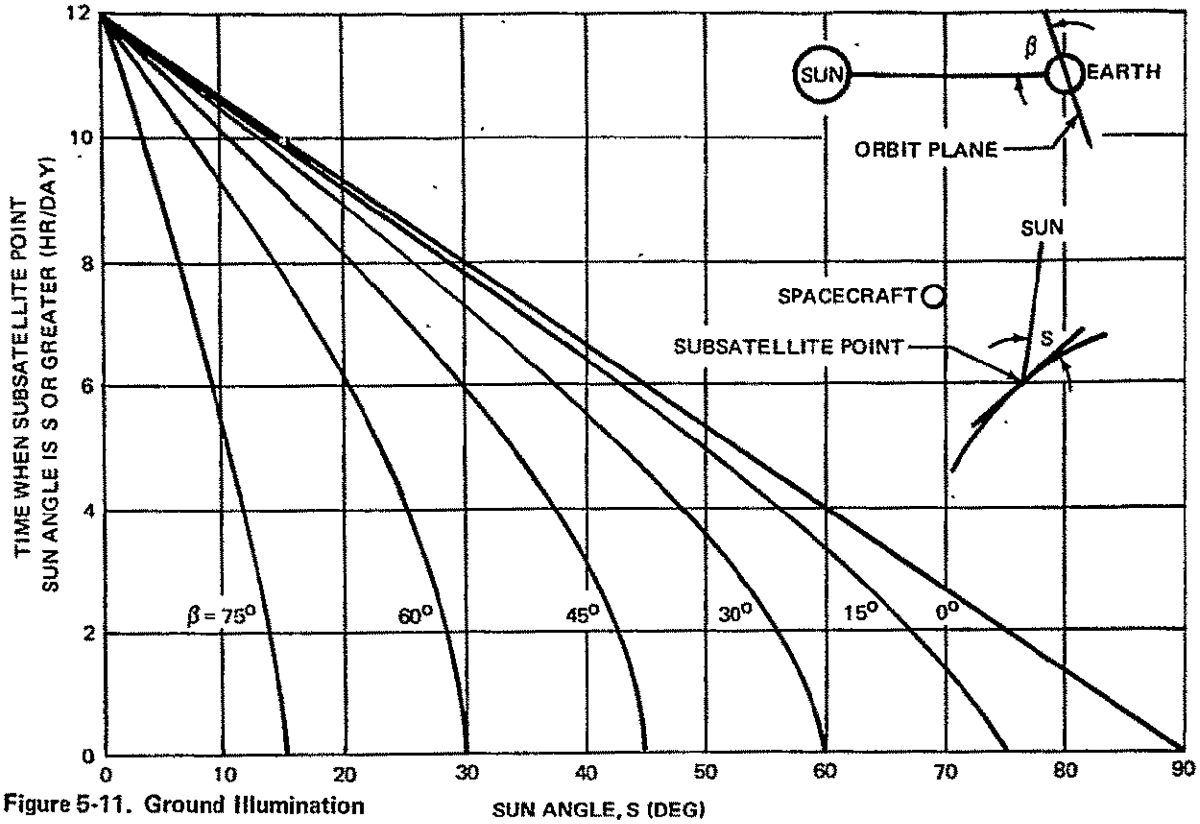


Figure 5-11. Ground Illumination

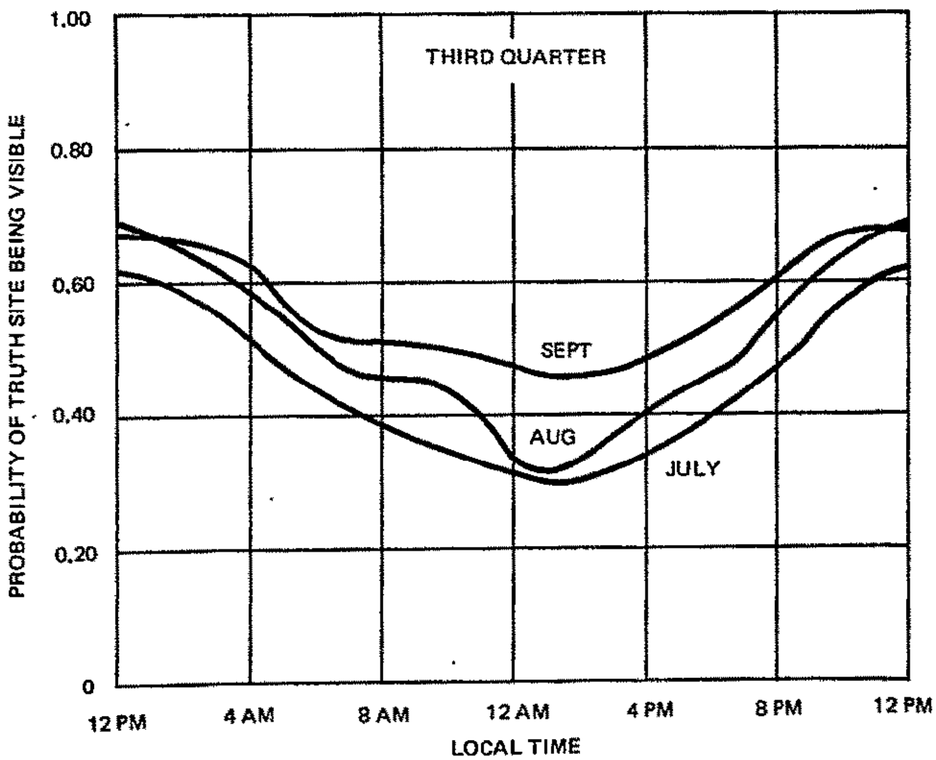


Figure 5-12. Cloud Cover Over Purdue Farms

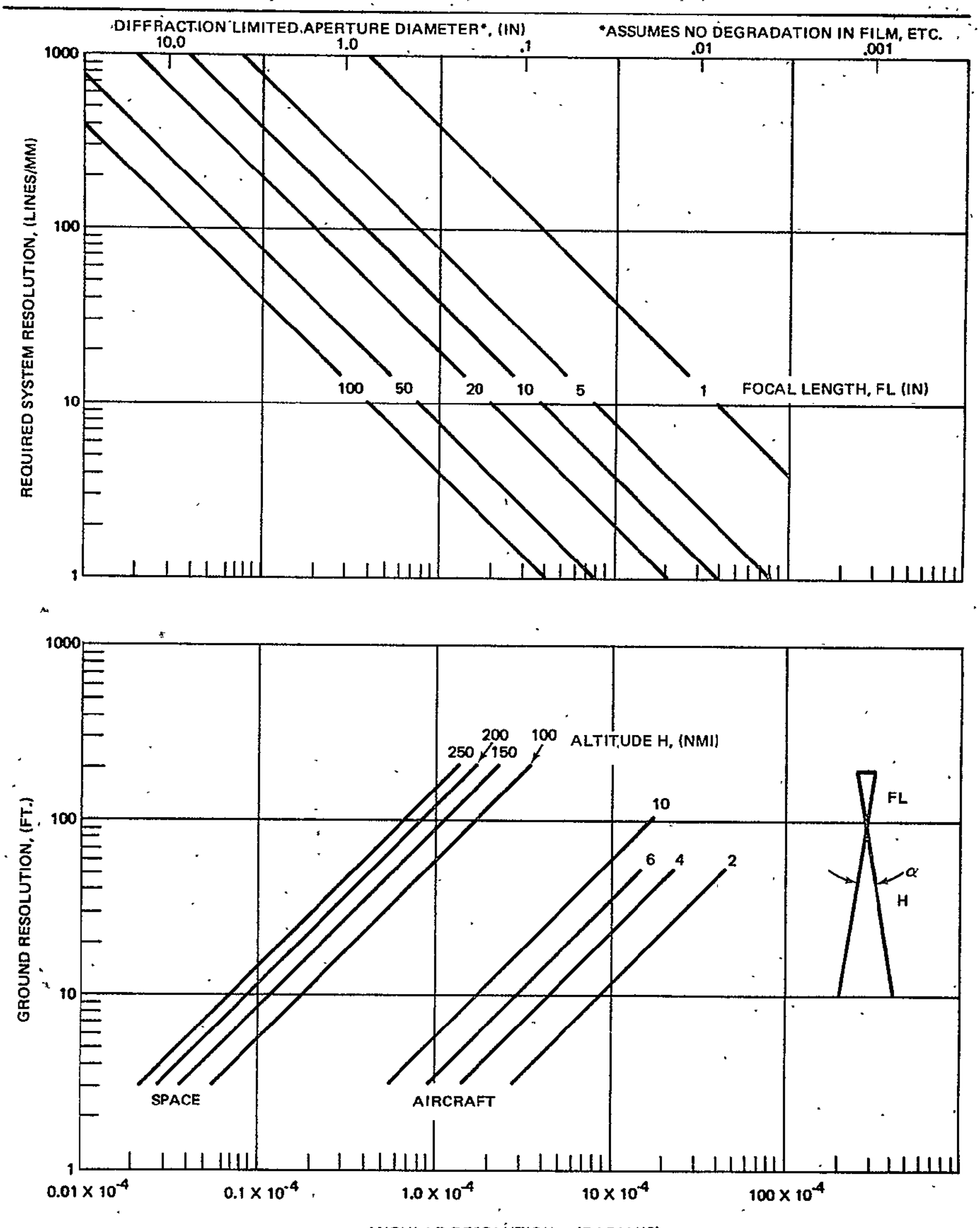


Figure 5-13. Nomograph: Optical Resolution

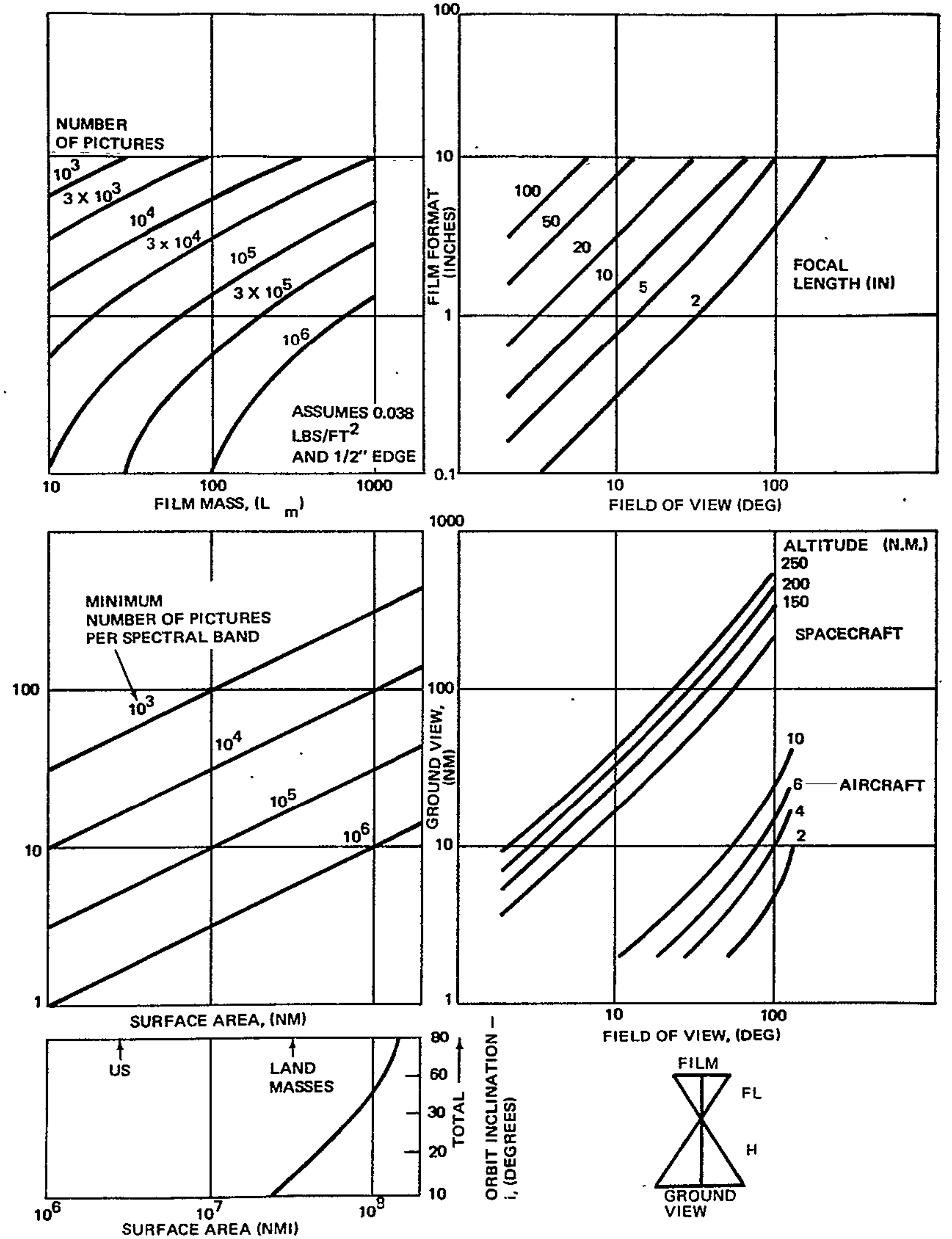


Figure 5-14. Nomograph: Film Weight Estimate

swathwidth may be combined to yield the number of photographs for each spectral band. At the bottom right, the swathwidth and orbit (or aircraft) altitude combine to determine the field of view, which together with the film format (upper right), specify the sensor focal length; or, given a focal length and field of view, one may specify the required film format. Moving to the upper left, a film weight is determined by the specified film format and the number of pictures, assuming a film density (0.038 lb/ft^2) and an unusable film area (1/2-in. edge). A few representative points have been identified in the surface-area chart: the United States, all the land masses, and the Earth's surface area. The total surface area covered by a spacecraft in low Earth orbit is also shown as a function of orbit inclination.

The quantity of data generated by a mapping mission and the subsequent time required to relay this information to the ground are shown in Figure 5-15. Ground resolution and area to be mapped determine the minimum number of bits for complete coverage. (This plot was generated, by assuming five bits per element). Given the number of bits and the downlink bit rate, or bandwidth, the time to transmit the data to the ground is found in the upper half of the figure. These three figures are not intended to supply detailed design information but rather to provide the planner with reasonable parametric estimates of sensor performance and data requirements.

Finally, an attempt has been made to provide a realistic use of some of the data presented in the preceding figures. The minimum time required to map both the world and the continental United States has been generated as a function of map scale and is presented in Figure 5-16. The ground-resolution to map-scale relationship was extracted from the requirements listed in Research Cluster 6-A/F-1. Assumptions made in creating this figure include a 9-in. film format and a film resolution of 150 lines per mm, and that there is no cloud cover. Orbit altitudes were restricted to the 100 to 300 nmi range and altitude/inclination combinations were chosen such that the ground traces did not repeat. A 90-degree inclination was selected for mapping the world and a 55-degree inclination was selected for mapping the United States. To minimize the time to map the United States, the initial ascending-node

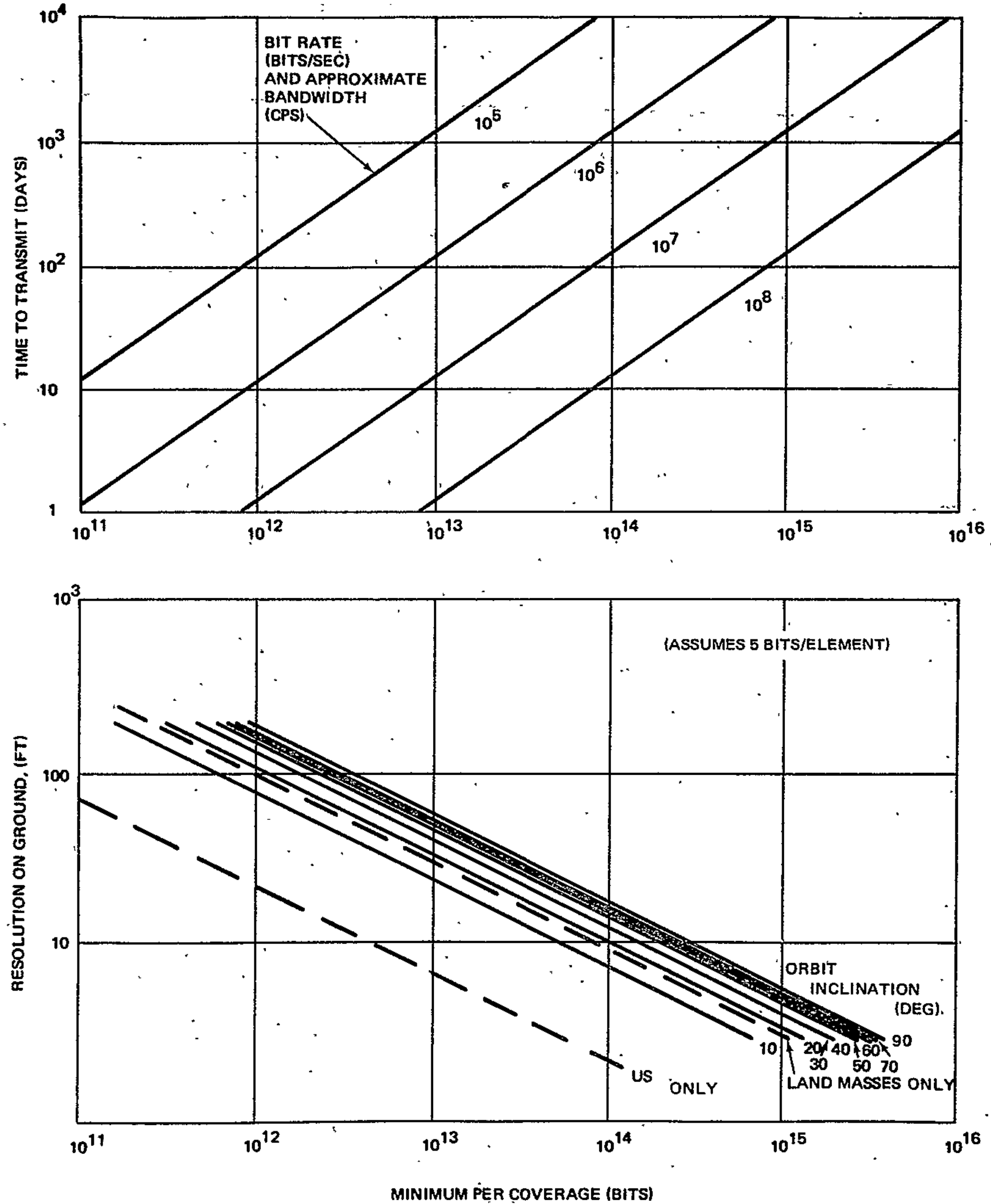


Figure 5-15. Data Quantity—Earth Viewing

location was so chosen that the first leg of the target is to the east coast of Florida. Because of the orbit regression rate, this curve terminates at approximately 12 days and thereafter approaches the world mapping curve.

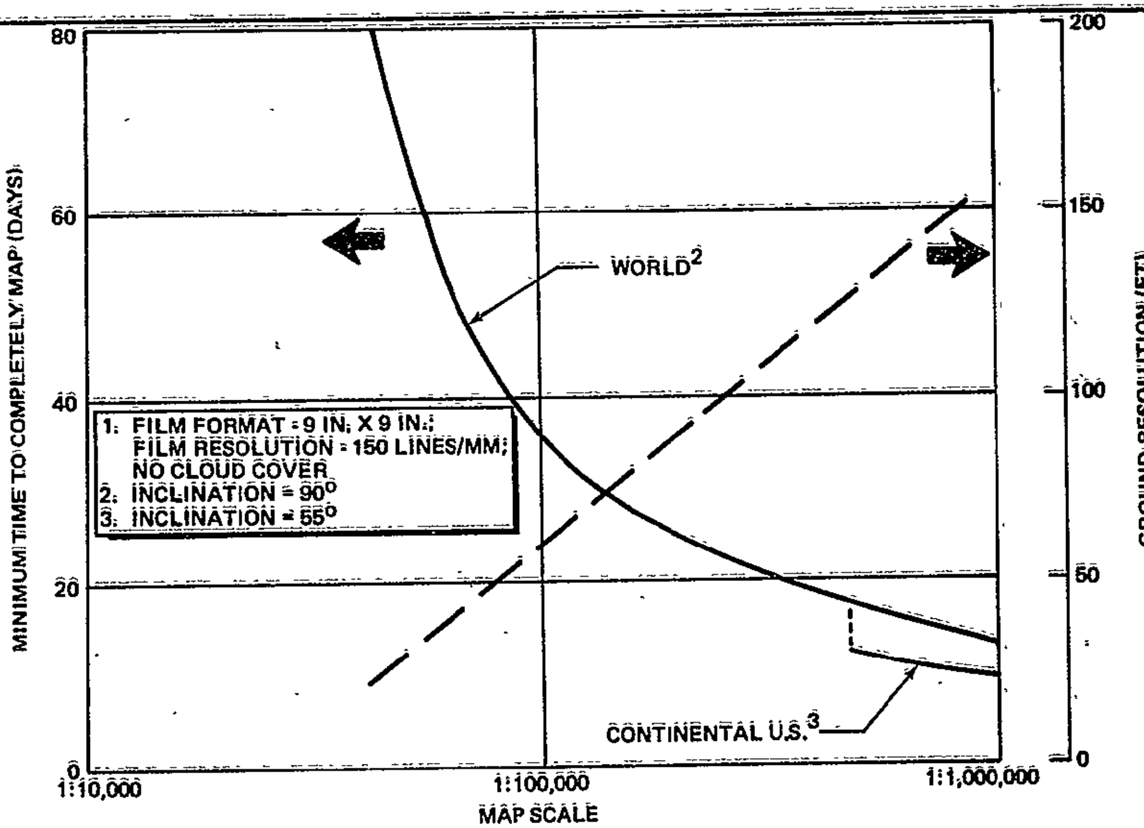


Figure 5-16. Minimum Time to Map[1]

5.3.2 Spacecraft Environment

A subject of considerable importance in mission planning but about which only limited data is usually available is the spacecraft environment. The specific environments discussed in this section are radiation from both natural and onboard sources, meteoroids, the background brightness level outside the spacecraft, atmospheric density, and the acceleration level inside of the spacecraft. These environments impose constraints on the operating regime for manned spacecraft, influence spacecraft design, and restrict experiment operations or degrade sensor performance. The discussion, in each case, emphasizes the impact of the environment on spacecraft or experiment, rather than defining the environment. The main purpose of this section is to alert the mission planner to problems arising from the effects of the environment on spacecraft design and sensor performance.

The constraints the environment imposes on the orbital operating regime are graphically illustrated in Figure 5-17. At low altitudes, the relatively dense atmosphere results in high orbit-keeping propellant consumption to overcome drag and therefore precludes long-term operations. At medium altitudes, the spacecraft is in the Val Allen radiation belts and receives high radiation dose rates. This high level of radiation restricts manned flights to short durations in this region. Practical, long-term manned operations are therefore limited to a narrow altitude band (200 to 300 nmi) in low Earth orbit or to very high altitudes above the Van Allen belts (synchronous altitudes or higher). Although not germaine to the environment discussion, the orbit inclination operating regime defined by current Eastern Test Range launch and range-safety constraints is also shown. The plane change requirements are prohibitive for low inclinations. The range safety corridors are shown on the figure.

The radiation environment exterior to the spacecraft may impact experiments with sensors located outside of the spacecraft. Equally important is dose-level information that deals with the radiation-sensitive experiments inside of the spacecraft. The dose level inside the spacecraft, however, is design dependent. To give the mission planner some idea of the magnitude of the dose levels, Figures 5-18 and 5-19, which were developed for the Space Station Study*, are presented as representative of the dose levels that might be experienced. Figure 5-18 indicates the radiation dose received by an inorganic receptor (i.e., film) at various locations within a space vehicle. Biological dose is shown for the same Space Station design over the projected orbital operating regime in Figure 5-19. The dose received from the onboard

*Space Station - Preliminary Systems Design Data, Supporting Analyses, Volume III, Book 1, MDC-G0634, MDAC, July 1970.

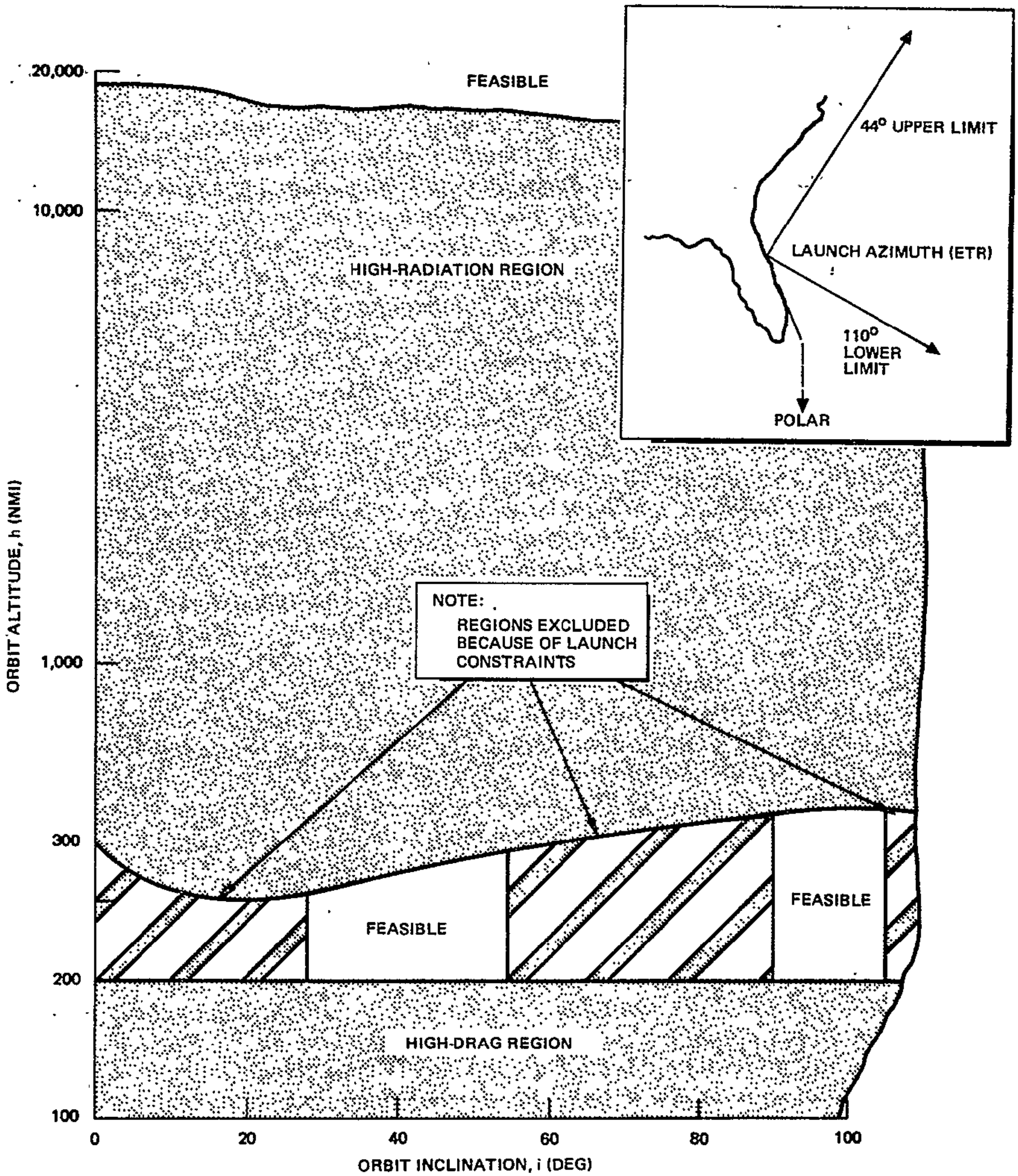


Figure 5-17. Manned Spacecraft Operating Regime

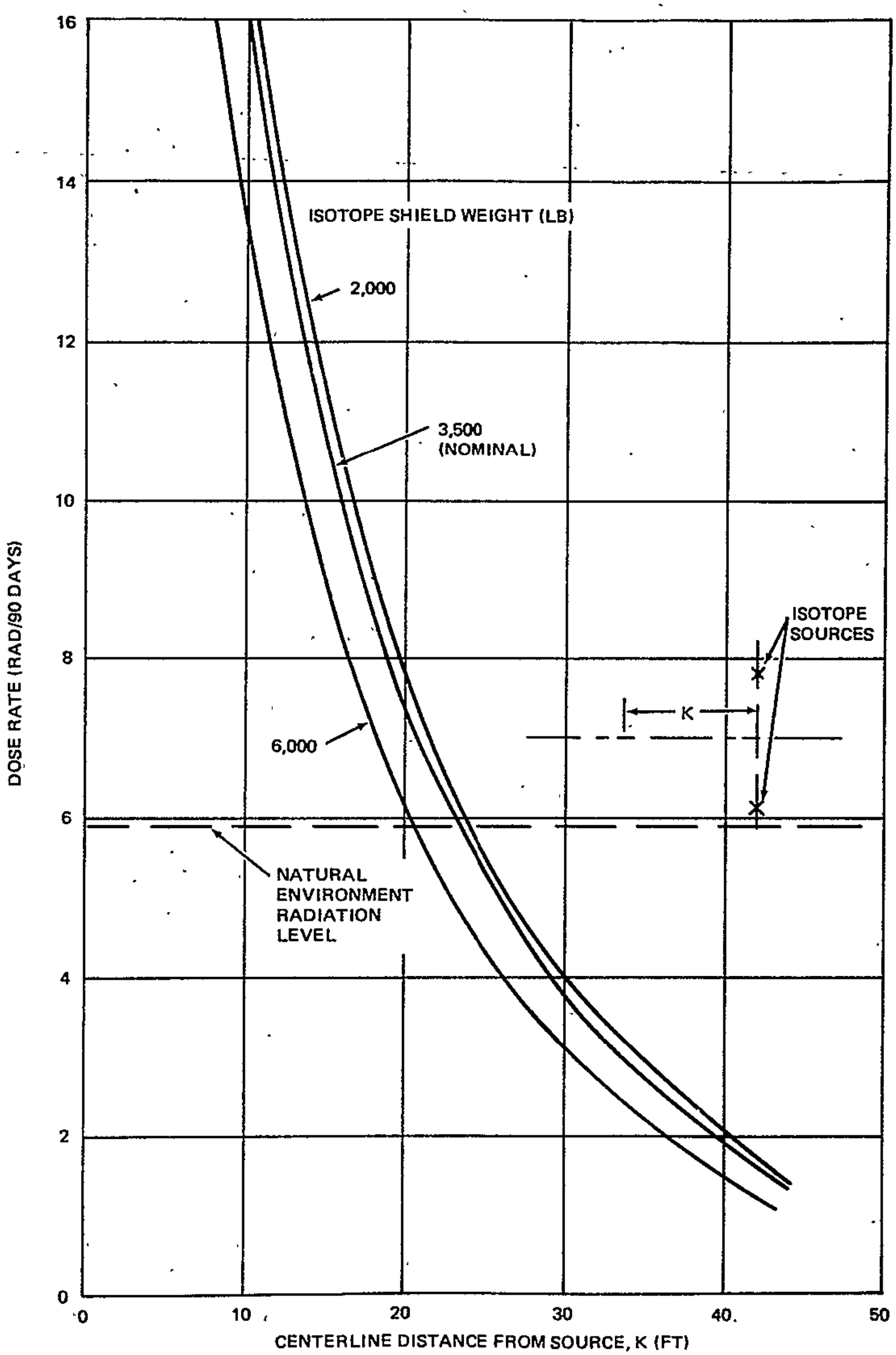


Figure 5-18. Dose Within Spacecraft From Isotope Source

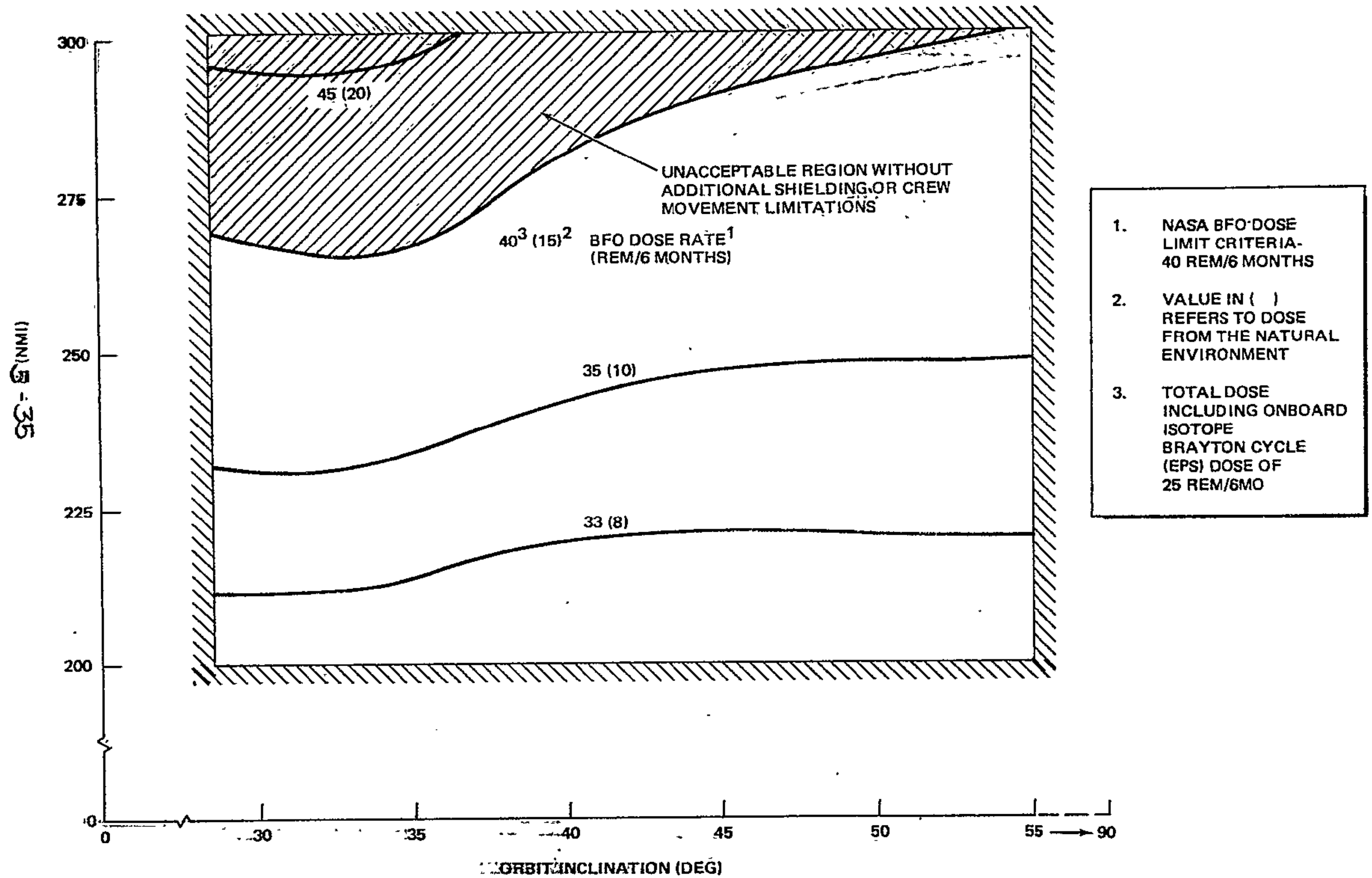


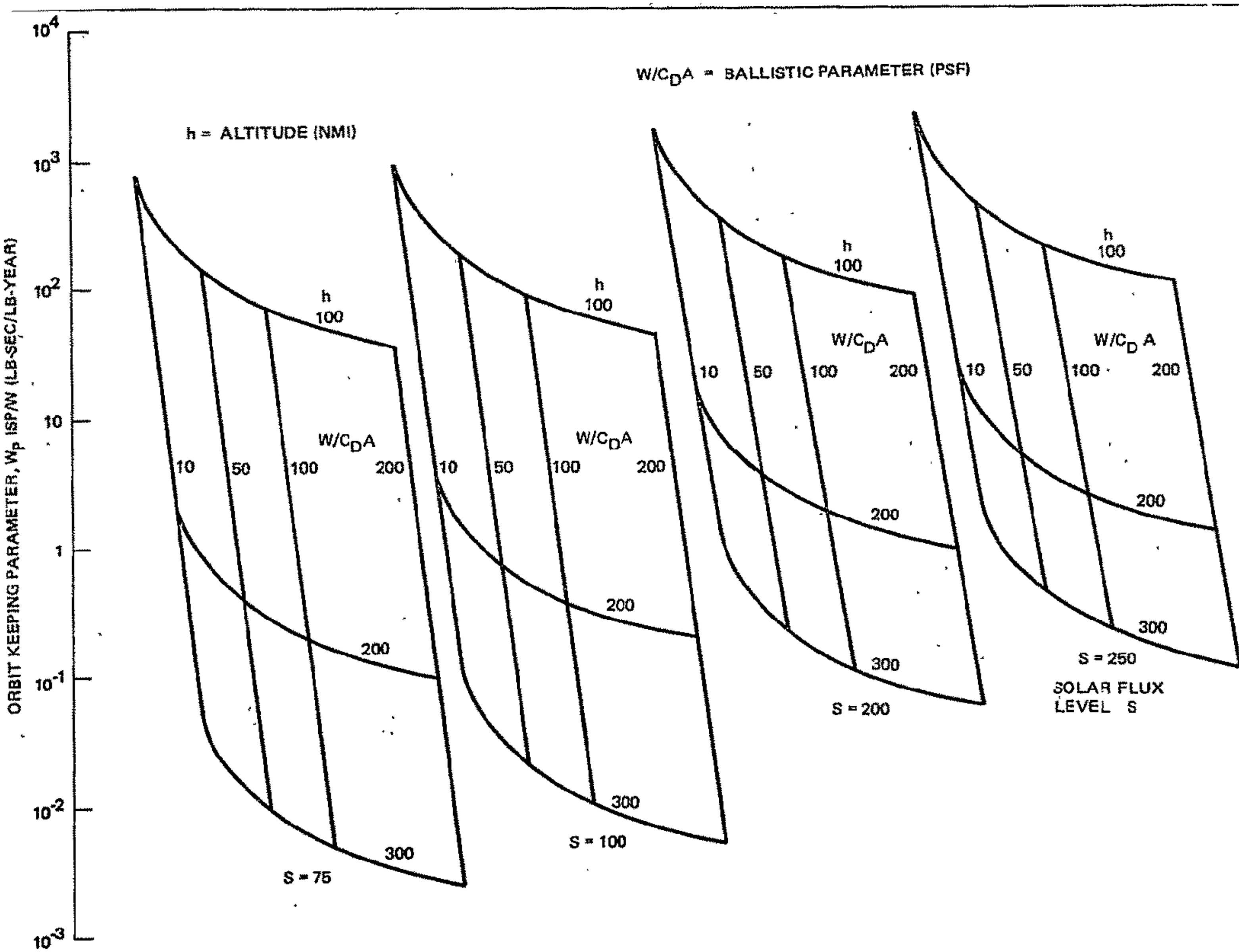
Figure 5-19. Spacecraft BFO Dose Contours for Orbit Envelope

isotope source (consisting primarily of gamma rays and neutrons with energies on the order of 1 MeV) constitutes a large percentage of the total dose. It is possible to make a significant reduction in the dose from the onboard source at a reasonable weight penalty. However, much greater weight penalties are necessary to produce a comparable reduction in the dose from the natural environment. Experiments that require radiation-sensitive film or include susceptible biological specimens must be given special consideration.

At altitudes below 200 nmi, orbit decay rates resulting from the drag produced by the tenuous atmosphere require corrective action. The energy expended in this effort is measured in terms of orbit-keeping propellant. A reasonable approximation to the energy expended is obtained if the corrective impulse is set equal to the impulse lost through drag. Orbit-keeping propellant consumption is illustrated in Figure 5-20 where a propellant expenditure index, propellant weight times specific impulse/total weight ($W_p I_{sp}/W$) has been plotted as a function of orbit altitude and ballistic parameter ($W/C_D A$) for several values of solar flux level. (Atmospheric density, and therefore drag, vary over the 11-year solar cycle. This variance is usually measured in terms of the solar flux level.) Since the $W/C_D A$ of a spacecraft is generally known, or can be predicted with some degree of accuracy, the propellant required for orbit keeping can be calculated by determining the propellant expenditure index from the $W/C_D A$, the altitude, and the projected value of average solar flux level; and then multiplying the index by the total weight-to-specific-impulse ratio. These orbit-keeping data have been generated for preliminary planning purposes, and the analyses do not contain sufficient depth for use in detailed design studies.

Meteoroids present a hazard not only to externally mounted experiment equipment, but also to crewmen engaged in EVA activities. In Figure 5-21, the NASA-derived meteoroid flux recommended for design studies is shown.

The danger to a crewman is described by the probability that his suit will be penetrated by a meteoroid. Assuming that the suit has an exposed surface area of 25 sq ft, to be capable of protecting the experiment against meteoroids


W/C_DA = BALLISTIC PARAMETER (PSF)
h = ALTITUDE (NMI)
ORBIT KEEPING PARAMETER, W_p ISP/W (LB-SEC/LB-YEAR)
10^4
10^3
10^2
10
1
10^-1
10^-2
10^-3
h
100
W/C_DA
10
50
100
200
300
S = 75
S = 100
S = 200
S = 250
SOLAR FLUX
LEVEL S

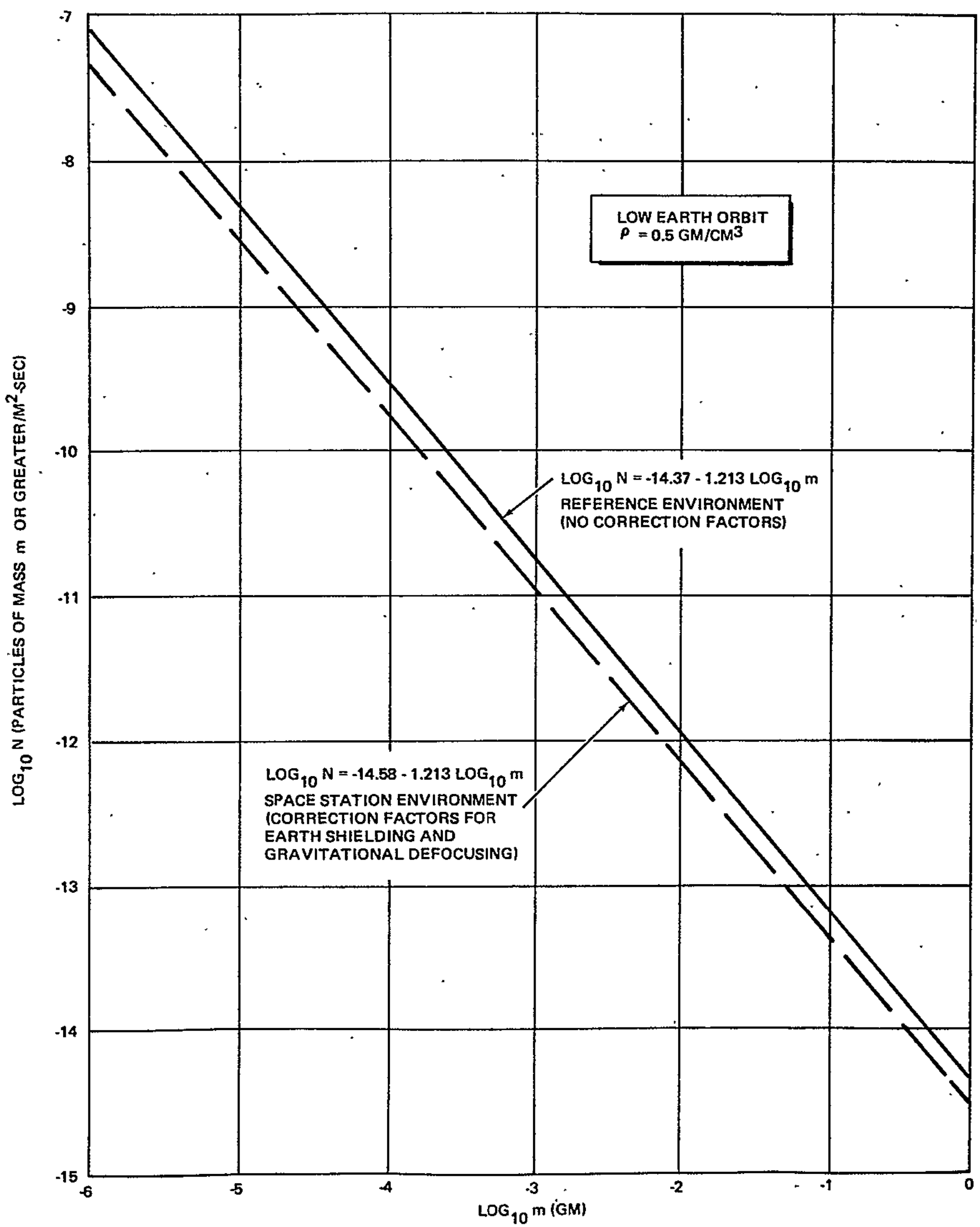


Figure 5-21. Meteoroid Environment

with a mass of less than 1×10^{-5} grams*, the penetration probability to astronauts performing EVA tasks is approximately 1×10^{-4} per hour or 0.2 per 2000-hr man-year. Although the probability of penetration is low for a short exposure, an extensive experiment program with a requirement for a large aggregate of EVA tasks may be unacceptable from the standpoint of crew safety. Long-term external storage of experiment equipment susceptible to damage from a meteoroid puncture may require design changes. Figure 5-21 provides the data necessary for determining the penetration-probability versus design-solution if ballistic limit data for the design solutions are available.

In the Space Astronomy discipline, the brightness environment constrains the capability of sensors in the visible region of the electromagnetic spectrum. The relative brightness (with respect to the sun) is shown in Figure 5-22 as a function of sun position**. The range of expected brightness is shown for a typical space station design where the brightness is relatively high due to sunlight scattering on coalesced spacecraft affluents. For comparison, the background brightness observed in Gemini V and Gemini VI are also identified, and OGO III data have been included as representative of the brightness to be expected in the vicinity of a detached module. This isolation of the telescope from man allows the observation to be made in an environment that approaches the natural level from coronal and zodical light.

Many experiments require specific acceleration levels or demand that the level be lower than some threshold value. Ranges of acceleration levels that could be expected for a typical space station*** are shown in Figure 5-23. These accelerations arise from a variety of diverse sources, and, in general, are random in direction and of extremely short duration. This environment is depicted in Figure 5-24, where an acceleration history has been constructed.

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*W. E. McAllum, Development of Meteoroid Protection for Extravehicular Activitv Space Suits. Presented at the AIAA Hypervelocity Impact Conference, May 2, 1969.

**Orbital Astronomy Support Facility (OASF) Study. Vol. IV, Task C, DAC-58144, Orbital Astronomy Support Facility Concept, Book 1 of 3, MDAC, June 28, 1968.

***Space Station - Preliminary Systems Design Data, Supporting Analyses. Volume III, Book 1, MDC-G0634, July 1970.

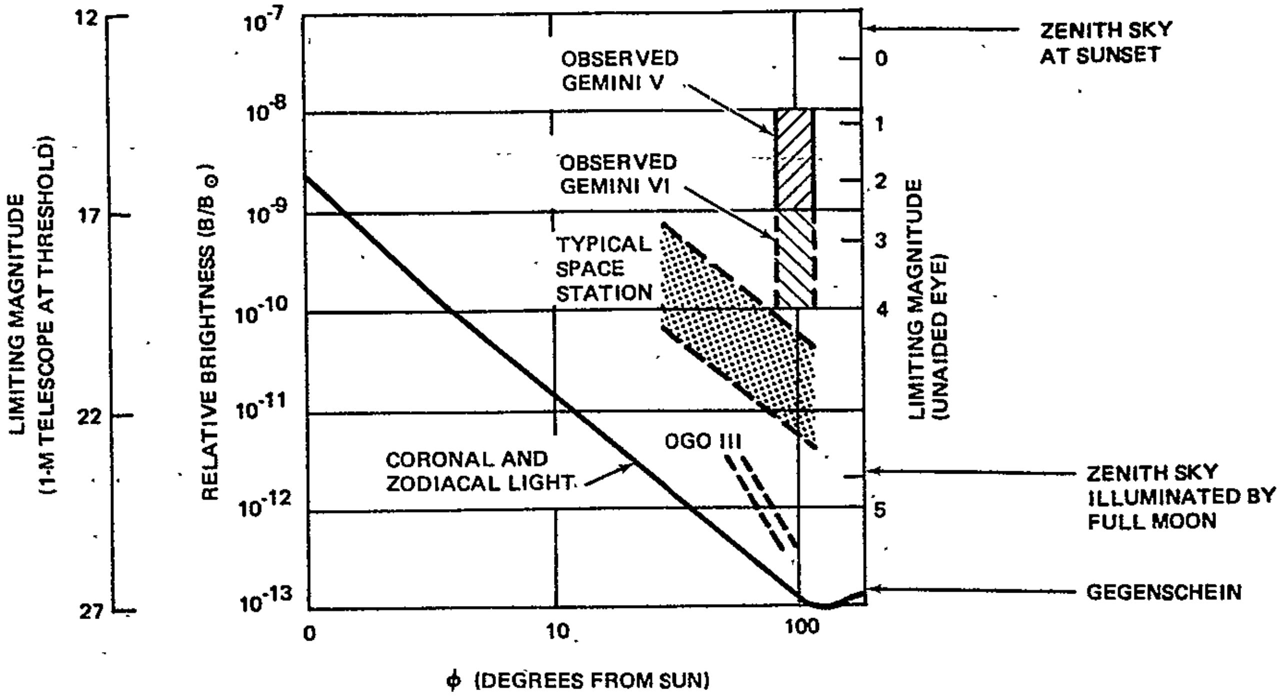

Figure 5-22. Radiance Distribution Comparison

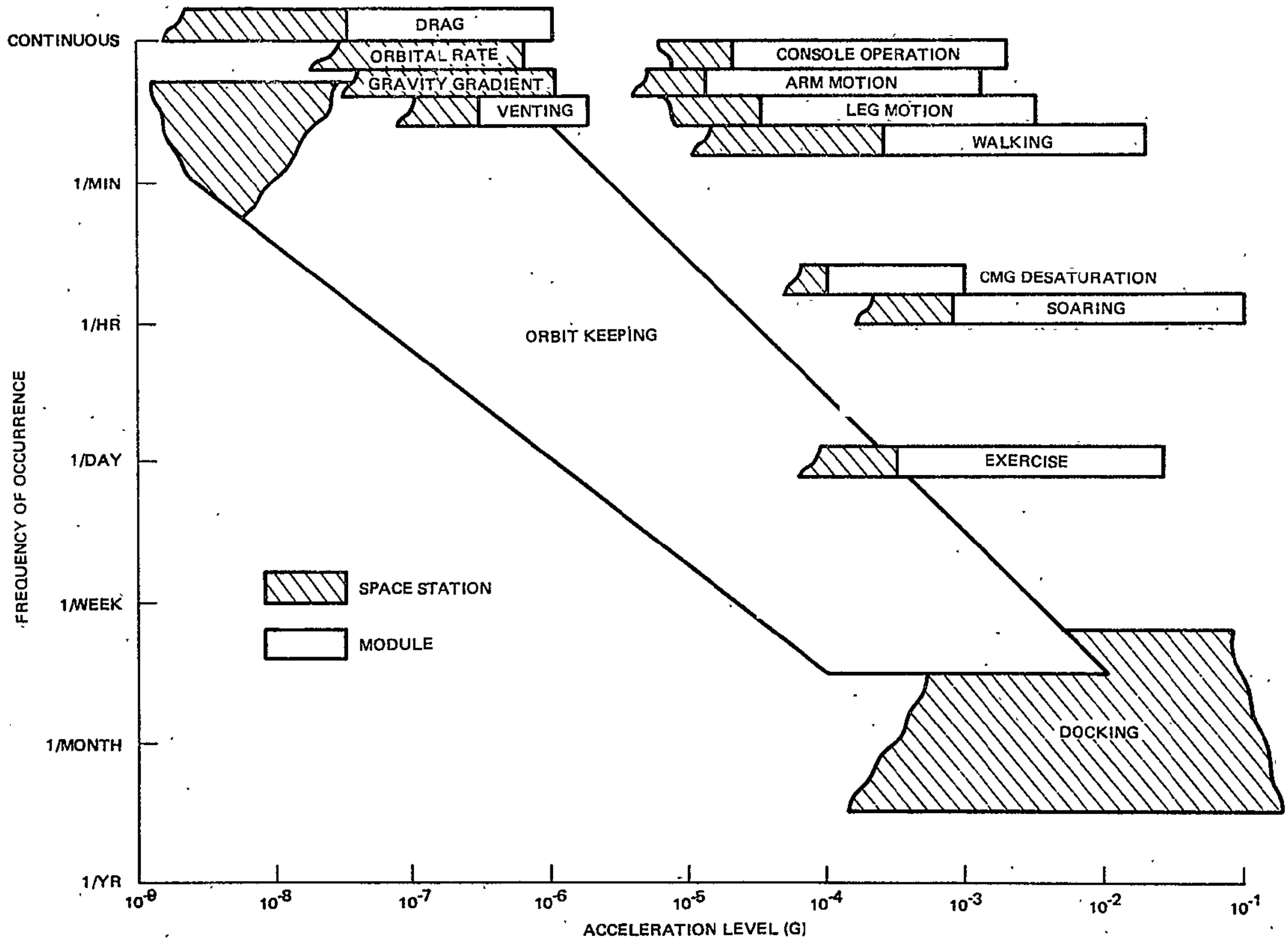

Figure 5-23. Accelerations Due to Disturbances

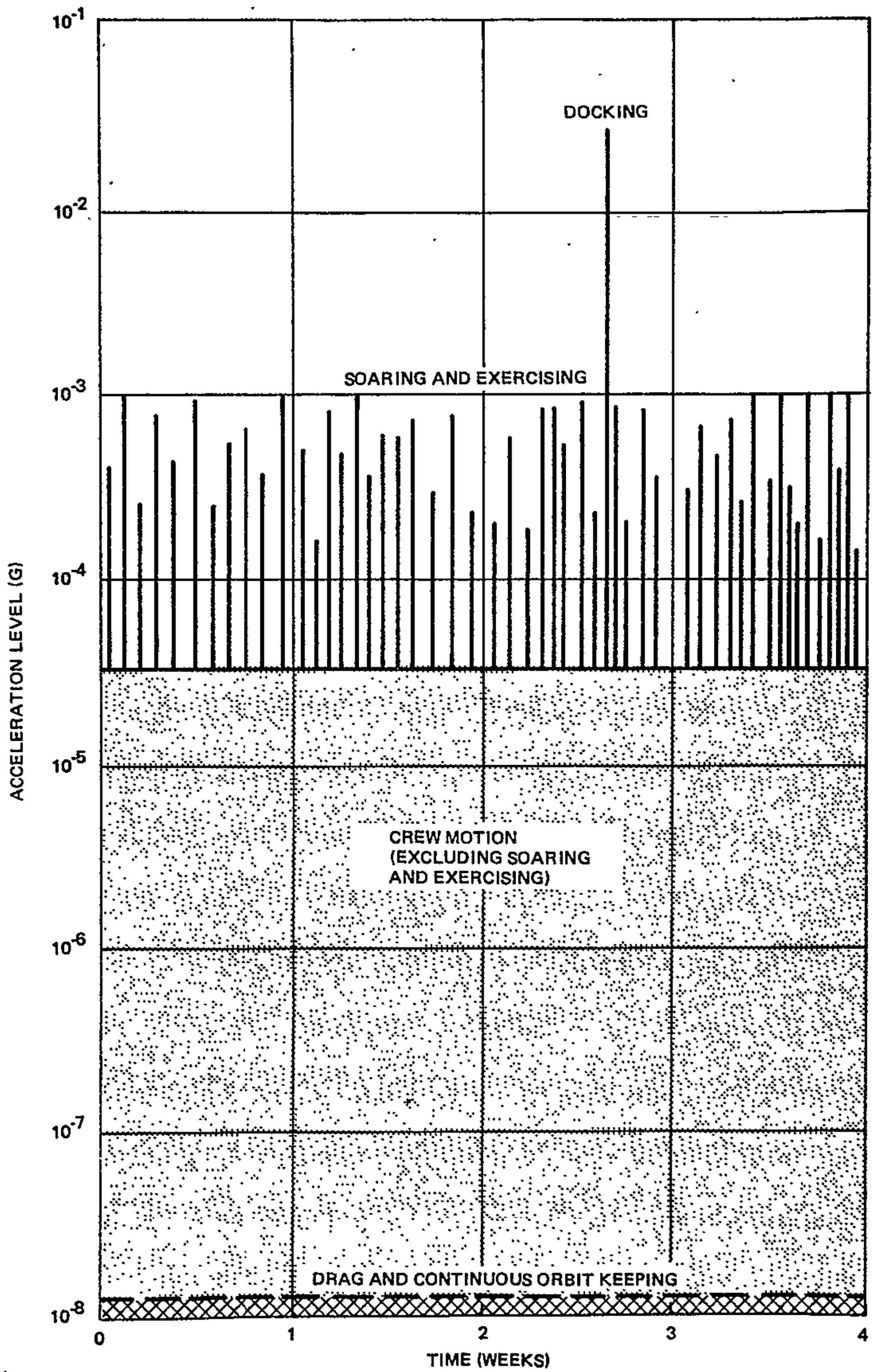

Figure 5-24. Typical Acceleration History

Some reduction in these acceleration levels can be obtained by restricting crew motion during critical experiment operations. The capability for unidirectional low-level acceleration is usually provided by a centrifuge. If the size of the equipment or some other feature precludes the use of a centrifuge, a thrust level capable of accelerating the spacecraft for the required time is needed. Since many different acceleration levels are specified, a variable thrust level would be required, and this capability has not been provided in previous space station designs.

5.3.3 Spacecraft Characteristics

An approach has been developed that links spacecraft characteristics to experiment requirements. This approach is predicated on the assumption that the primary factor in designing a spacecraft and in accomplishing an experiment program is crew size. Certainly, the number of crewmen available to support experiments constrains both the scope and depth of an experiment program. Based on data from several in-depth NASA-funded studies, a relationship between crew size and the number of crewmen assigned to the experiment program has been estimated and plotted in Figure 5-25.

Following this approach one step further, total gross spacecraft weight has been plotted as a function of crew size (Figure 5-26). The curve slope is derived from both existing and projected spacecraft. Using these two figures, a preliminary estimate of spacecraft size can be obtained from experiment program requirements. The crew time requirement from a candidate experiment program identifies the number of crewmen necessary to support experiments. From Figure 5-25, the crew size, including both operational and experiment support personnel, is then determined. With crew size known, the spacecraft weight is found from Figure 5-26. This approach can be extended to include both power and volume as a function of crew size.

The purpose of this analysis is to provide the mission planner with broad data that will at least give him representative spacecraft characteristics as a function of experiment requirements. The accuracy of these planning relationships is illustrated by the data spread in Figure 5-26. The actual relationships between crew size and spacecraft characteristics are currently undefined but are functions of such parameters as booster capability and designers cleverness, and are constrained by such intangibles as safety requirements and program costs.

To remind the mission planner faced with gathering the elements of his overall system, a sampling of system and subsystem characteristics has been included. Figure 5-27 represents a compendium of candidate launch vehicle performance sheets. These sheets are available in a variety of forms from the vehicle manufacturers. The applicability of candidate power systems and their projected weight-to-power relationships are shown in Figures 5-28 and 5-29. Stability and control system (SCS) candidates and their attitude-hold capabilities are presented in Figure 5-30. Propulsion systems that provide or supplement attitude control, and their ranges of applicability are shown in Figure 5-31. To illustrate the requirement for detailed design studies in support of the initial mission planning exercise, a list of considerations of the contamination problem that must be investigated prior to selection of the propulsion subsystem is included as Table 5-3. These data, although by no means complete, should provide the mission planner with an initial estimate of spacecraft characteristics and the subsystem trade studies that will be required in a detailed design study of a spacecraft to accommodate the candidate experiment program.

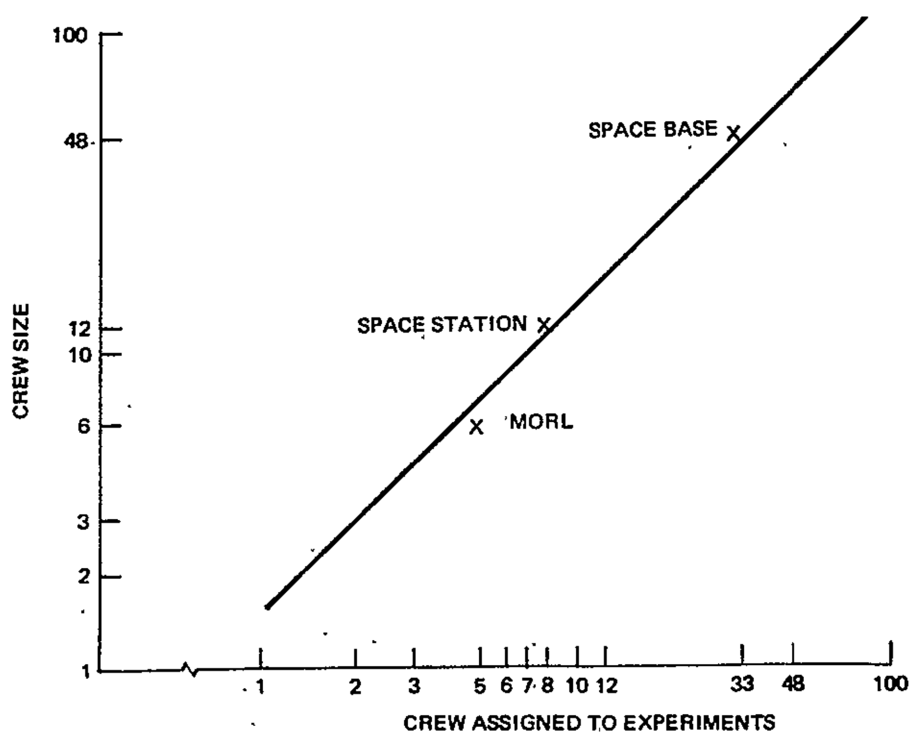

Figure 5-25. Relationship Between Total Crew Size and Experiments Crew

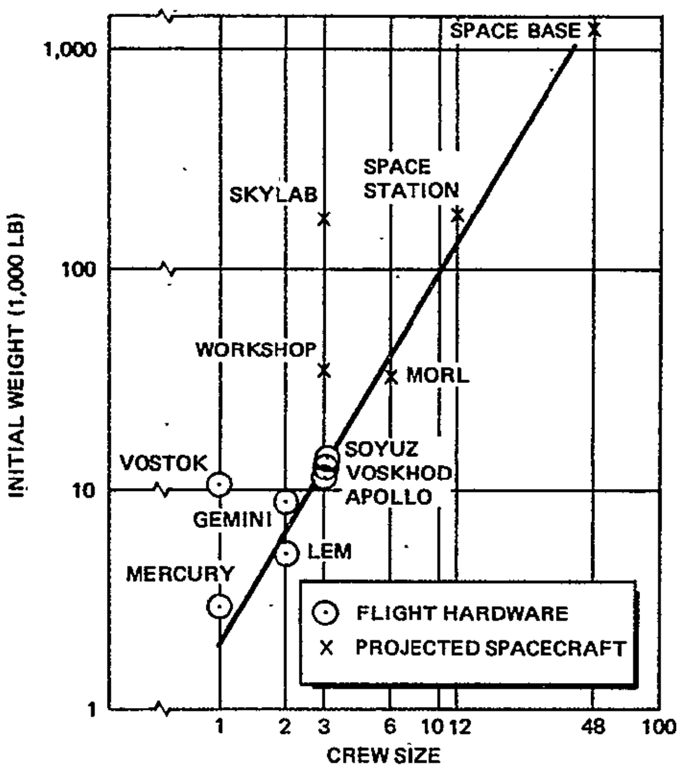

Figure 5-26. Relationship Between Crew Size and Spacecraft Weight

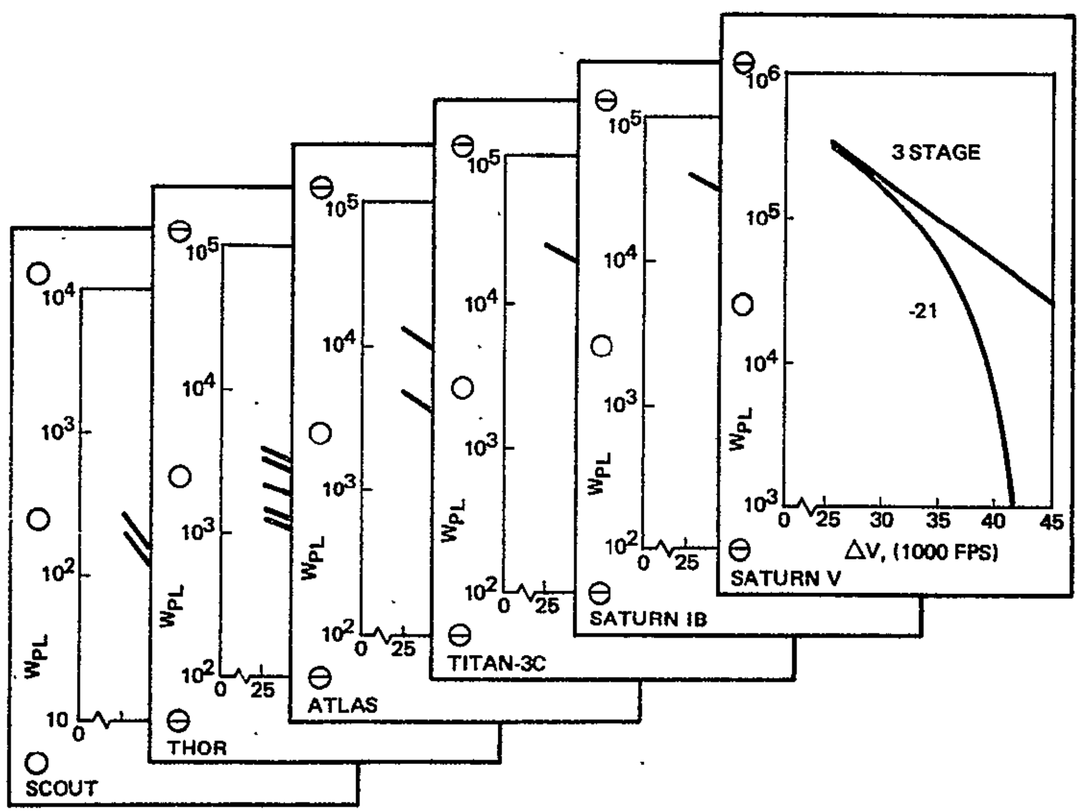

Figure 5-27. Parametric Performance Data

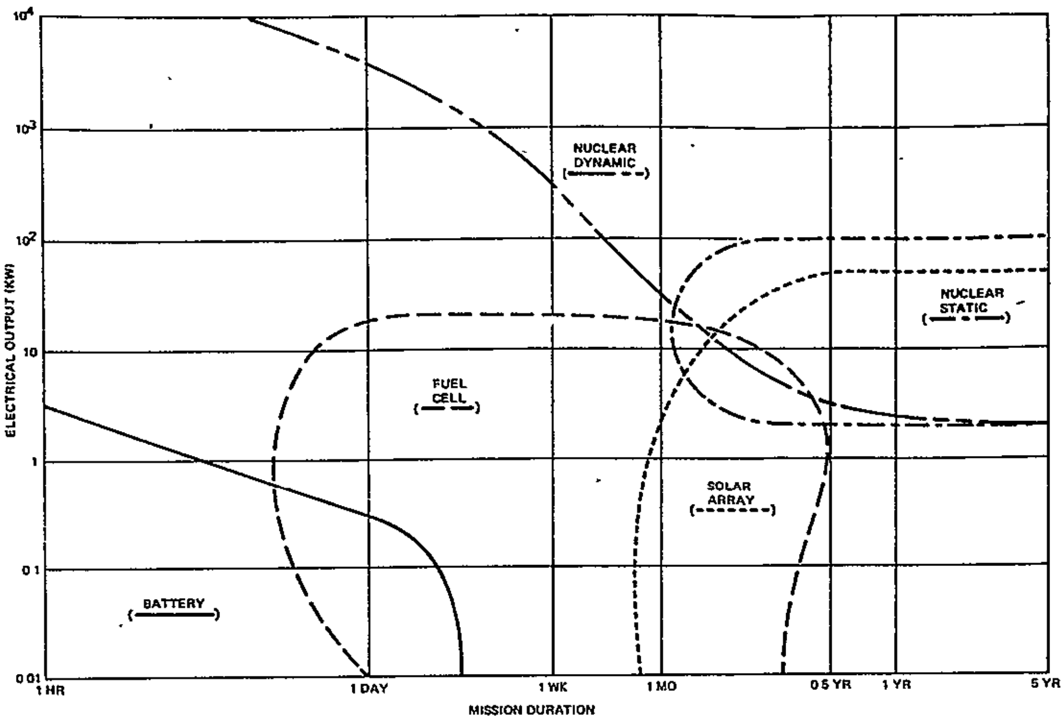

Figure 5-28 Energy Source as a Function of Power Level and Duration

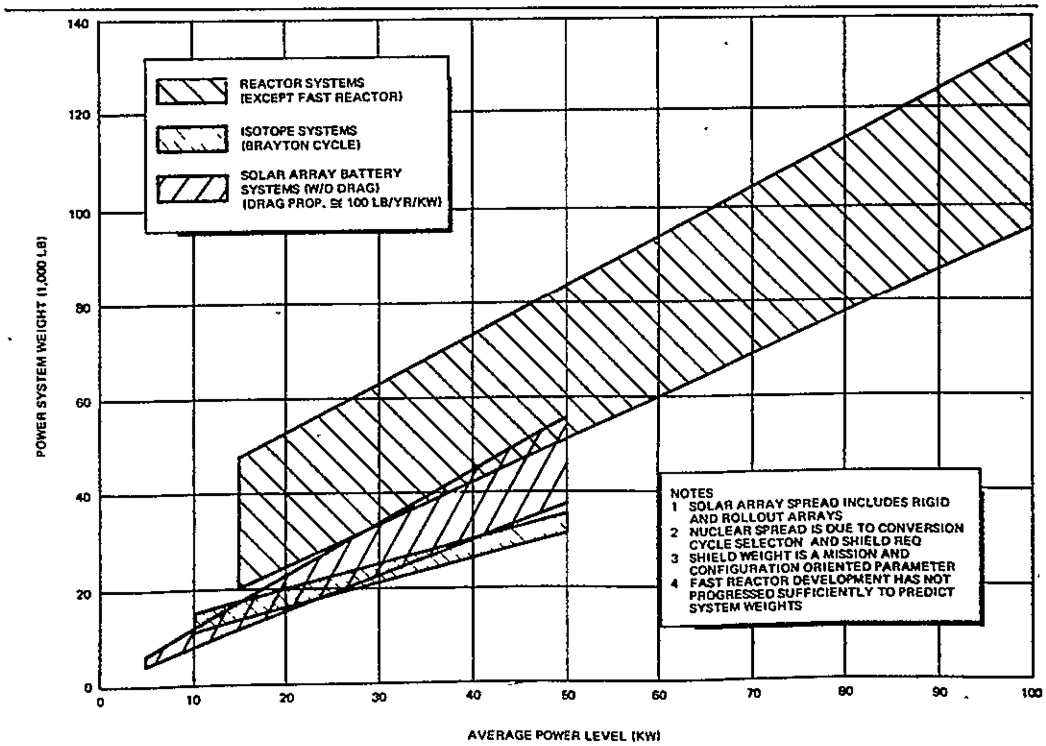

Figure 5 29. Estimated Power System Weights

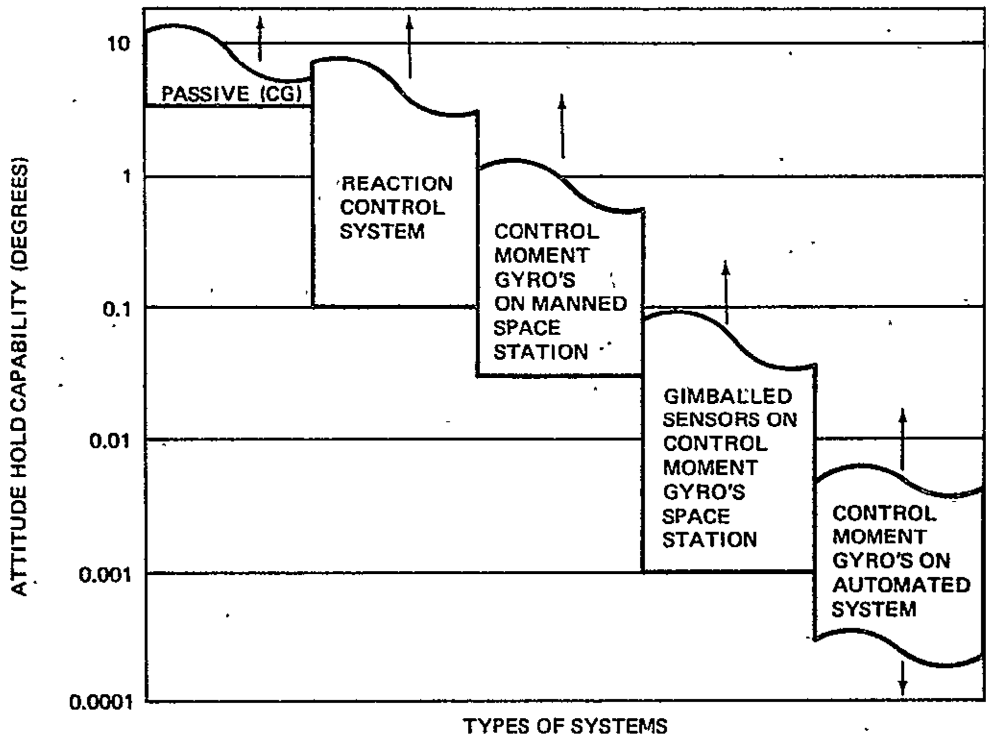

Figure 5-30. Spacecraft Control System Candidate Capabilities

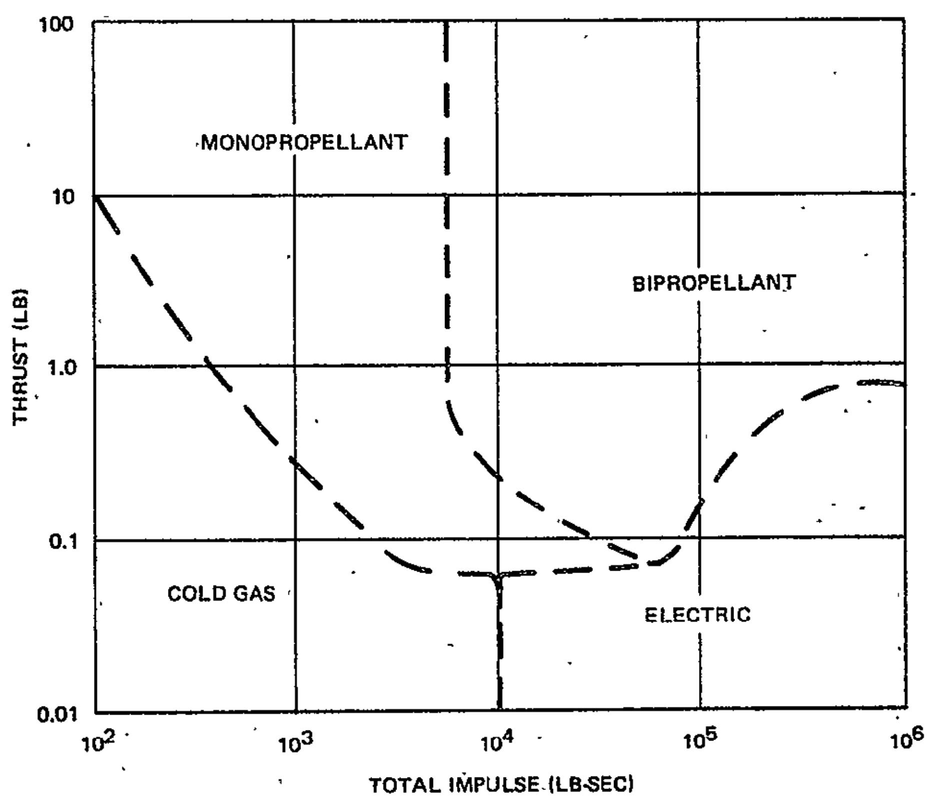

Figure 5-31. Attitude Control Propulsion System Candidates

5.4 IMPACT OF CREW CAPABILITIES ON MISSION PLANNING

Overall mission planning is a complex process of which the definition of crew requirements must be considered an integral part. As the planning process continues over a period of time, any of the three research mission's fundamental elements - objectives, system characteristics, or operational considerations - is subject to change on the basis of tradeoff studies. Definition of crew requirements is included as one of the experimentation operational considerations in mission planning. Because of its potential impact on vehicle design, the crew mission time lines and the selection and training requirements must be estimated during the earliest phases of mission planning.

Table 5-3

PROPULSION SUBSYSTEM DESIGN CONSIDERATIONS

(CONTAMINATION)*

1. The use of resistojets reduces the plume size by as much as a factor of 50 in comparison with conventional monopropellant or bipropellant RCS systems.
2. Biowaste gases (H_2O, CO_2, and CH_4) are the cleanest if run at conditions preventing CH_4 dissociation. Since dissociation also reduces thrustor life, eliminating dissociation is required by the propulsion system as well as by experiment considerations.
3. Ammonia resistojets produce N_2 and H_2 effluents only, and are acceptable for the majority of free-flying experiment clusters.
4. Monopropellant hydrazine is cleaner than bipropellant N_2O_4/MMH, but it may not be worth the performance penalty unless the experiments are in a direct line of sight with the thrustor centerline. This must be assessed separately for each mission.
5. Since most contaminating effluents are located on or near the thrust centerline, judicious placement and canting of thrustors can eliminate, or greatly reduce contamination potential.

*Propellant selection and system design involve many considerations besides contamination. Such factors as duration, resupply, maintenance, impulse requirements, and mission heavily influence system selection and design.

The steps in mission planning that are particularly crew-oriented, shown in Figure 5-32, include the required inputs and the output or product of each step.

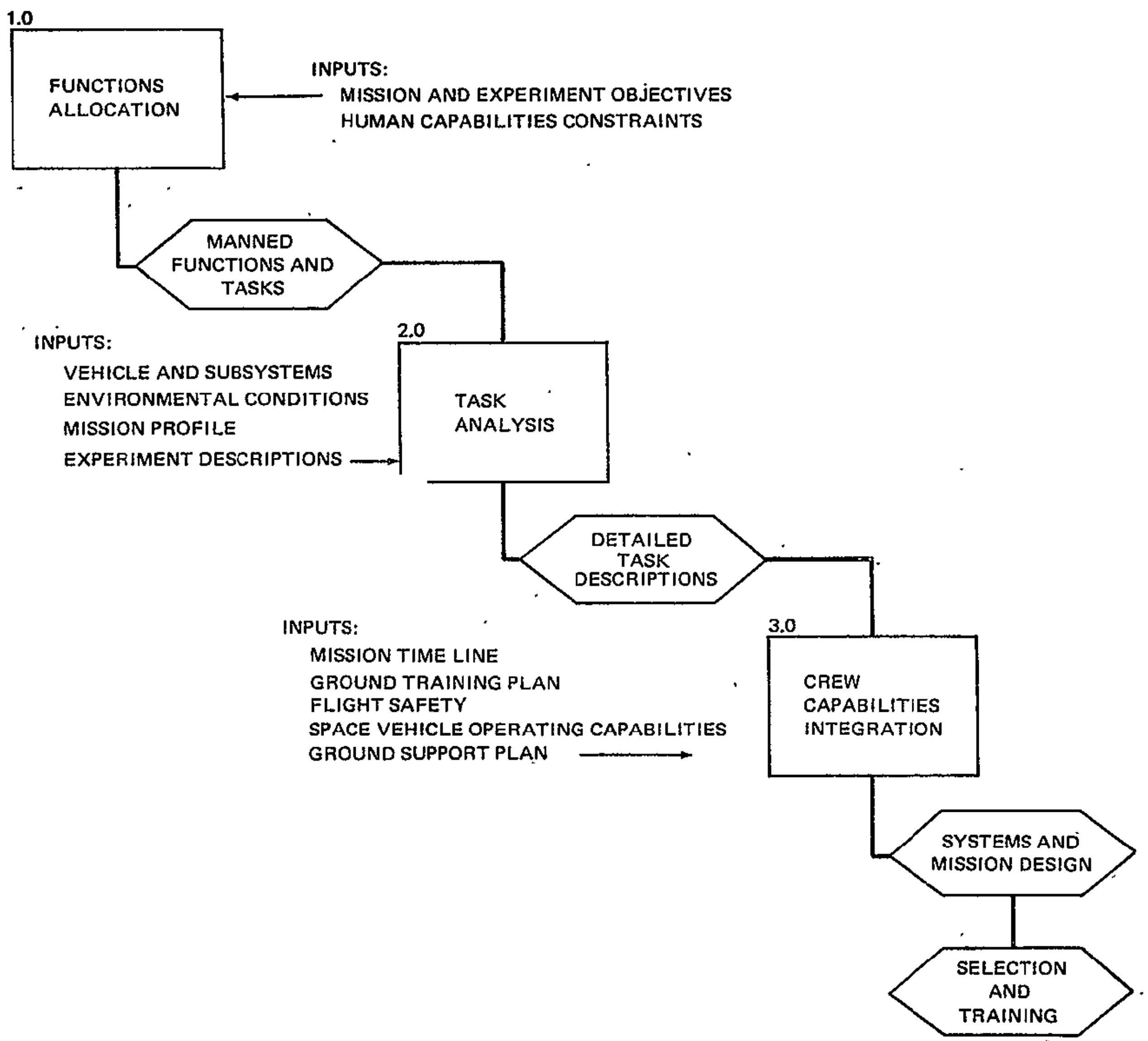

Figure 5-32. Crew Requirements Mission Planning Steps

The process shown in the figure is iterative and must begin early in the planning phase and continue almost until launch date or mission initiation. The first step, function allocation, is concerned with the initial identification of the functions or tasks that man will perform during the inflight mission. It involves examination of all of the functions that the system must perform to meet its objectives and of allocating them, either in whole or in part to man or machines or in some cases to ground elements. Function allocation must consider many factors, the most important of which is to evaluate the relative capability of man in comparison with machines. Since a basic knowledge of man's specific capabilities in a terrestrial environment is generally available, the process may begin. Table 5-4 summarizes preliminary specifications, based on the available literature, describing selected sensory, sensorimotor, and mental functions, along with potential applications of these functions in scientific experiments in orbit. Comparing man's capabilities with those of machines, it is possible to identify functional areas where either man or machine is superior.

Tables 5-5 and 5-6 provide some guidance in this respect. Table 5-5 provides preliminary data on man-versus-machine choices for a sample of general functions. Table 5-6 gives a comparison of manned-versus automated operations of specific tasks in orbital photography. It should be pointed out that function allocation is not a precise, quantifiable process and must depend heavily on the skill of a knowledgeable analyst. In addition to data on human capabilities, the constraints that mission and experimental objectives place on function allocation is a critical factor. The time available to perform a function, the accuracy demands, and the competing functions that may take priority are examples of the types of constraints that must be considered. The output of this phase of the planning process is a list of manned tasks, stated in terms of what man does to achieve some end objective, such as operating spacecraft controls to establish and maintain required attitude and track.

A second step in this process, task analysis, is a logical extension of the first and involves the development of detailed descriptions of each of the tasks identified in Step 1. Task analysis is designed to describe what man

Table 5-4 (page 1 of 7)

SUMMARY OF SPECIFIC HUMAN CAPABILITIES

Function	Characteristics	Recommended Applications	Special Limits
Vision	• Acuity (Vision Angle Subtended) -General Target Detection ~50% Probability: 0.8 Min. >99% Probability: 1.4 Min. -Minimum Separable: 0.4 Min. -Vernier: 0.03 Min. -Stereoscopic: 0.025 Min. -Minimum Perceptible: 0.008 Min. (All at Background Luminance of 100 mL.) • Sensitivity: 10^{-5} mL (Adapted) • Frequency Range: 397-723 mμ • Critical Discrete Signal Rate: 50 cps Central, 20 cps Peripheral — At > 10 mL • Frequency Discrimination: 1 mμ at Sodium Line and at Constant Intensity • Field Coverage (from Center Line) -Head Fixed, Eyes not Fixed • Horizontal 165° each side • Vertical 66° up; 82° down	• Discrete Target Detection • Target Fixation and Motion Compensation • Cover Avoidance • Target Selection -Selective Aiming • Accurate Alignment • Pattern Recognition -Description -Comparison -Interpretation • Signal Detection in Noise • Color Evaluation -Color Correction • Photo Evaluation (Quality) • Photo Interpretation • Display Scanning • Stand-By Sensing	• Overload -Flash Blindness -Signal Frequency and Rate • Low Light Adaptation Time • Low Light Acuity • Low Light Color Perception

Table 5-4 (page 2 of 7)

SUMMARY OF SPECIFIC HUMAN CAPABILITIES

Function	Characteristics	Recommended Applications	Special Limits
	-Head and Eyes Fixed • Horizontal 95° each side • Vertical 46° up; 67° down • General: Very sensitive, stereoscopic paired sensors - automatically coupled for stereo with selective image fusion or automatic suppression of unwanted double images. Numerous automatic functions (aperture control focus, tracking, signal response).	-Warning Lights • Low Light Observation • Motion Detection	
Hearing	• Sensitivity: 2×10^{-4} Dynes/cm^2 at 1000 Hz • Frequency Range: 20-20,000 Hz • Frequency Discrimination: ±10 Hz at 500 Hz/56-64 Db • Discrete Signal Rate: TBD • Field Coverage: Spherical with moderate directional sensitivity • General: Sensors paired for stereophonic reception; several automatic functions including reflex tracking and noise suppression. Frequency (Pitch) matching is good but pitch identification a function of training. Perception	• Discrete signal detection in noise fields -Pattern recognition -Intelligibility • Signal Scanning • Stand-by Sensing -Warning Signals • Signal/Noise Adjustment • Adjust Aim for Maximum Signal • Frequency Matching • Beat Production	• Overload -Hearing Threshold Shift -Frequency Sensitivity Attenuation -Signal Rate • Frequency Matching with Signal Intensity Uncontrolled

Table 5-4 (page 3 of 7)

SUMMARY OF SPECIFIC HUMAN CAPABILITIES

Function	Characteristics	Recommended Applications	Special Limits
	of pitch varies with signal intensity. High frequency range attenuates with age and noise exposure.	• Voice; Code Communication	
• Kinesthesis, Proprioception and position sense	• Sensitivity (Kinesthesis) -Acceleration: $0.1-0.2 deg/sec^2$ Angular Acceleration with 10-15 Sec. Response for 75% Correct Detection of Direction: $0.4 deg/sec^2$ with 1 second response time (useful) threshold). -Displacement from Vertical in Zero-G: Lag of Response 40-50 seconds. -Vibration: Tangential at Fingertip: 10Hz at 10^{-2} G 800 Hz at 0.3 G • Special Functions: -Stereognosis: can determine shape by feel -Apply Graded Force -Assess Force Required	• Detect Random Motions • Detect Vibration • Manipulate Control with Calibrated Force • Identify or Describe Object without Visual Cue • Determine Resistance to Deformation or Motion	• Slow Response to Low Rate of Onset of Motion • Slow Response to Displacement from Vertical in Zero-G -No response without visual cue • Proprioception limited in Zero-G - Weight, Posture, Skin Pressure Cues Lost. • Inner Ear Sensors Relatively Easily Confused - Can Give False Information
• Olfaction	• Sensitivity: (Threshold) -Taste: 4×10^{-7} mol -Smell: 7×10^{-13} mol	• Detection of Air, Water, Food Contaminants • Identification of Substances by Taste or Smell	• Both Senses Easily Squelched • Discrimination of Individual Stimuli in Mixtures Poor.

Table 5-4 (page 4 of 8)

SUMMARY OF SPECIFIC HUMAN CAPABILITIES

Function	Characteristics	Recommended Applications	Special Limits
			• No Directivity • Identification of Stimuli a Function of Experience and Training
• Somatic	• Tactile: 0.5 x 100 msec. -Two Point Discrimination: • Fingertips: 2-3 mm • Body (Gen): 60-70 mm • Tongue: 1-2 mm • Pain: Not Quantitizable • Temperature: (At Sensor) Decrease of 0.004° C/Sec. Increase of 0.00-$^{\circ}$C/Sec. • General: These sensors are present in the skin of the entire body but distribution per unit area varies widely. Touch sensation is amplified in detection by movement of hair. Somatic sensors generally supplement proprioception and kinesthesis and contribute to fine, calibrated manipulations (along with small muscle proprioceptors).	• Sensing Surface Texture • Wet/Dry Sensing • Detecting Temperature Changes • Detecting Temperature Quality, Quantity • Very Fine Shape, Texture Discrimination • Detect Potentially Injurious Stimulus • Detect Inscribed Information without Visual Cue.	• Sensors Adapt quickly to low intensity signal and signal perception is damped or squelched
• Response	• Response Time -Simple: 0.2-0.3 Seconds -Reasoned: Depends on alterna-	• Emergency Actions • Signal Response - Especially random or	• Response Time Limits • Environmental Interference

Table 5-4 (page 5 of 7)

SUMMARY OF SPECIFIC HUMAN CAPABILITIES

Function	Characteristics	Recommended Applications	Special Limits
	tives and decision time; Est. 5-10 sec. for simple 2-3 choice reaction	Unprogrammed • Response to Complex inputs requiring interpretation, variable decisions or incompletely defined actuations	High Data Rates • -Multichannel -Sensory Overload
	• Rate Limits -Essentially Single Channel (May respond to multiple inputs but not simultaneously) -Frequency depends on response time	• Response to Partial information requiring inductive logic • Response to totally unprogrammed events	
	• Conditioning -Trained -"Instinctive" -Experience -Reinforcement	• Response to discrete signal in noise	
• Integration and interpretation • Decision making • Prediction	• Makes use of partial information • Large data bank -Related data (Training) -Apparently unrelated data (Experience)	• Operational and command decisions • Trouble-shooting • Warning signal evaluation	• Multiple channels of programmed data with defined solutions can be handled - but slowly and for short periods only (~1 Hr.)
• Opinion • Higher mental function	• Rapid Interpretation of unprogrammed data • Information analysis limited	• Corrective actions in unprogrammed situations	• Training and experience very important in maximizing application of these functions

Table 5-4 (page 6 of 7)

SUMMARY OF SPECIFIC HUMAN CAPABILITIES

Function	Characteristics	Recommended Applications	Special Limits
	by sensor limits • Capability for inductive reasoning • Capability to adapt to constantly changing situation • Capability to take advantage of serendipitous events • Make value judgments	• Adaptation to new operational conditions • Data evaluation -Selection -Compression -Summarization -Sorting -Selected transmission • Predict result from partial data-extrapolate • Form personal opinion -Relate to other (hypothetical) situations Relate to other's reactions • Instant reporting	• Response/sensory overloads - number of decisions per unit time is limited.
• Sensorimotor response	• Manual Dexterity -High Refined -Automatic feed-back and calibration with built-in sensors • Long duration low level force application • Self repairing and maintaining • Neuromuscular response time total ~2 sec. minimum	• Vehicle control in critical operations (e.g. rendezvous and dock) • Delicate manipulations • Application of graded force • Controlling in constantly changing condition or in unpredictable	• Neuromuscular Fatigue • Force application limits -Long duration -Short duration -Bursts • Response Time Finite

Table 5-4 (page 7 of 7)

SUMMARY OF SPECIFIC HUMAN CAPABILITIES

Function	Characteristics	Recommended Applications	Special Limits
		events	
	(including perception, integra tion and activation times)	Fine control of instruments	
		Tracking with motion compensation	

Table 5-5 (page 1 of 2)

MAN-MACHINE ALLOCATIONS
(SENSOR FUNCTIONS)

Function	Example	Recommended Choice	Reason
Discriminate between several inputs in close time proximity (but not simultaneously).	Monitoring progress of countdown	Man	Man can abstract and combine several cues, i.e.; visual, auditory, tactual, and kinesthetic. Routine use of machines is too expensive.
Detect signals in high noise level.	Cathode ray tube displays. Communications equipment. Routine radio jamming.	Man	Man can detect masked signals through background noise. Machines are disrupted by interference and noise sources.
Detect low-energy levels. Also detect slight changes in energy.	Weak radar signals. Weak audio signals.	Man	The absolute thresholds of man approach the random noise of nature, and the slightest changes are detected.
Scanning to detect signals.	Monitoring plane position. Indicator scope.	Man	Man can shift his attention rapidly. Computer programming of this capability is very expensive.
Detect predictable and frequent events, especially over long durations.	Monitoring equipment readiness.	Machine	Man is easily distracted, bored, or fatigued.
Detect unusual or incidental events.	Detect equipment malfunction through smell of smoke.	Man	Machines do not select incidental intelligence.
Out-of-tolerance condition.	Strip Chart to monitor parameters during test	Machine Man	If small tolerance. If level of discrimination required is large.

Table 5-5 (page 2 of 2)

Function	Example	Recommended Choice	Reason
Long-term storage and retrieval of meaningful complex material to reach a decision.	Design of a launch pad. Responding to enemy evasive tactics. Decision to attack target.	Man	Man can act selectively from a large number of possible variables. Man can respond to changing dynamic situation; machines require reprogramming, MAN CAN OPERATE IN THE ABSENCE OF COMPLETE INFORMATION.
Insight, discovery, or problem solving. Unpredictable situations.	Teaching (or learning) new concepts.	Man	Man can make inductive decisions and generalize from few data; machines have no equivalent capacity.
Pattern recognition and interpretation.	Sonar. Wave forms of test oscilloscopes	Man	Man can recognize and use information redundancy (patterns) of the real world to simplify complex situations.
(INFORMATION APPLICATIONS)			
Perform in isolated and/or monotonous surroundings.	Monitor missile status in a silo.	Machine	Man cannot tolerate long periods without sensory stimulation-otherwise vigilance and performance degenerate.
Perform in noisy and uncomfortable surroundings.	Monitor the temperature of a heat treatment process.	Machine	Machines can perform monitoring and actuating functions regardless of noise or "uncomfortable" surroundings. Man's performance suffers in these situations.
Actuate many things at once (parallel operation).	Transmission of missile alert status to several direction centers.	Machine	Man is very limited in the number of simultaneous responses he can make.

Table 5-6 (page 1 of 3)

COMPARISON OF MANNED VERSUS UNMANNED PERFORMANCE OF ORBITAL PHOTOGRAPHY

Function	Manned	Unmanned
Cloud cover determination	Determined by astronaut through use of PTS (pointing and tracking system) photograph alternate target or stop camera if primary target is obscured.	Cannot be determined precisely - use prediction and weather satellites. Primary target only will be photographed at every overpass if predicted cloud cover is below approximately 40% regardless of whether target is obscured or not.
Surveillance and target acquisition.	Astronaut uses PTS	No surveillance. Target acquisition is based upon prediction.
Exposure compensation for sun angle and terrain changes	Automatic with manual backup. Manually trim based upon observing developed film or to correct photometer output when there is a high percentage of cloud cover or to pick up areas in cloud shadows.	Automatic only. Backup could be programmed through.
Stop operation of selected film strips	Controlled by astronaut to conserve film due to cloud cover or minimize redundant.	May not be practical due to uncertainty of cloud cover and actual ground area covered.
Optical focus and alignment	Manually performed	Automatic. Failure to function properly may seriously degrade photography.
V/H (Velocity/Height) sensing	Automatic with manual backup with PTS	Automatic. Failure will seriously degrade quality of photography.

Table 5-6 (page 2 of 3)

Function	Manned	Unmanned
IMC (Image motion compensation) roll compensation	Automatic. Manual monitoring consideration might be given to some form of manual backup	Automatic. Failure will seriously degrade all photography at all angles other than the compensated angle at which roll compensation device stopped operating
Film Drive IMC	Manually monitor film travel Velocity through indicators. Astronaut trimming of individual film drives may be provided.	Record film travel velocity for each film strip on magnetic tape for delayed transmission to ground film velocity trim probably not possible. Film drive IMC could be monitored by driving a V/H compensated grid over the lens of a TV camera which is used to record the scene being photographed on video tape for related transmission to ground.
IMC errors due to automatic V/H sensor locked on clouds	Manned monitoring of automatic V/H sensors. Manually override if sensor is locked on clouds.	Automatic. Resolution on some film will be decreased due to automatic system locking on clouds.
Film jams	Film jams less probable because of simplified film transport system. It may be possible to correct film jam if it occurs.	Complex film transport system. Higher probability of jam and it cannot be corrected.
Film handling	Simplified mechanism since cameras can be manually loaded and unloaded and manually placed in processor and/or data containers.	Complex mechanization involving long film transports and complex drives and controls.

Table 5-6 (page 3 of 3)

Function	Manned	Unmanned
Film development	Possible to check effects of vibration in exposure, filters and different types of film for optimum resolution.	Possible to mechanize but at great increase in complexity.
Data return	Man can evaluate data and assign priorities for discard, editing, and return.	All data must be returned and evaluated on the ground.

does, when he does it, how long it takes, what skills are required, what information he needs, and what equipment support is required. In some cases it becomes necessary to divide individual tasks into task elements for ease of analysis, but this technique should be used only when it is necessary to use a lower level of detail for ease of analysis. The task should be described at the highest level of specificity at which the description can be accurate and useful. In addition to the input of manned tasks from the preceding step, this step requires an input of the best available information on the candidate vehicle and its subsystems, the environmental conditions to which man will be subjected, a proposed mission profile, and the payload experiment descriptions. As these data are played against the functional tasks identified earlier, changes in the form of task additions, deletions, and revisions may take place. The detailed task descriptions, which are an output of this step, provide the basis for the integration of crew capabilities into an overall mission and program plan.

Integration of crew capabilities data into the total program (Step 3) is the most critical and most difficult task in conducting this phase of the mission planning. The task data generated as a result of the first two steps, although accurate and desirable, is essentially an ideal solution which must face the realities of time, cost, feasibility, and availability. It is in this step that most of the alteration to the task structure takes place, and where available vehicle configuration details along with constraints of available training time and the available manpower pool and many other factors must be considered. It is also in this aspect of mission planning that analytical techniques for making the appropriate decisions are most lacking. Some preliminary tools are available, however, such as the Langley Research Center Space Station Mission Simulation Mathematical Model and other independently developed computer programs that have demonstrated some capability in performing total crew mission scheduling. The LRC model*, as a set of integrated computer programs, is illustrated in Figure 5-33. To augment the computer programs now available, techniques and programs are required that cannot only evaluate mission task data

*Broadening the Application of a Space Station Mission Simulation Mathematical Model. MR-0-233, prepared for the Langley Research Center, NASA, by the Fort Worth Division of General Dynamics, November 1, 1968.

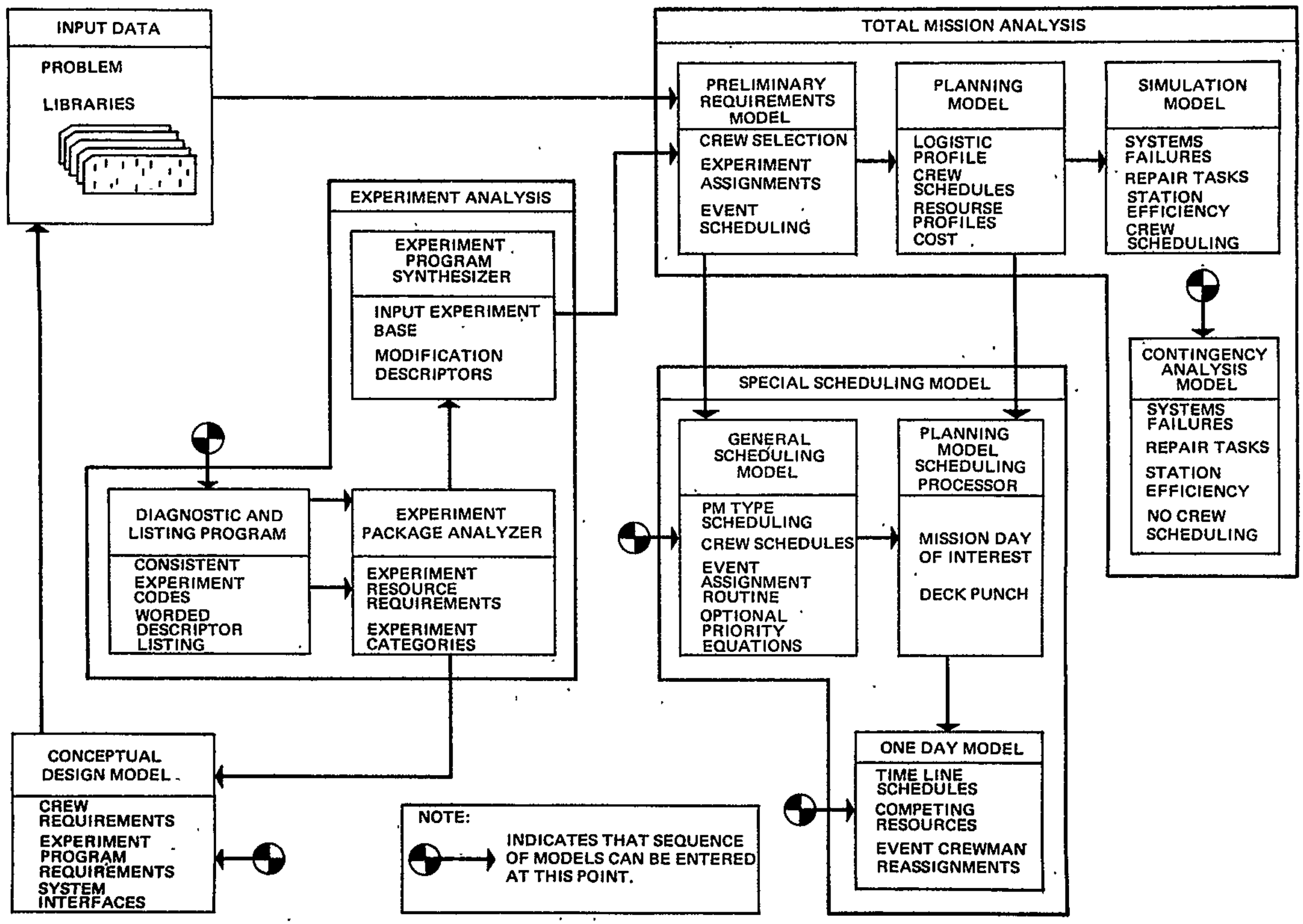

Figure 5-33. Model Concept and Utilization Sequence

against all known in-flight mission and systems constraints but also generate crew-selection criteria compatible with available training time.

5.5 DATA MANAGEMENT SYSTEM CONSIDERATIONS

The ultimate purpose of manned space missions, as addressed in this study, is to collect scientific information (raw data) and to deliver these data to the principal users in their most usable form. This section contains a general treatise on the principal considerations of mission data management necessary to provide information support to space research. The planning information presented is derived as a result of active participation in a number of space experiments data system studies, the most recent being a NASA-sponsored Phase B Space Station definition study.*

As a preliminary to mission data management, Subsection 4.4 and Appendix F presented the analysis and definitions relating selected data characteristics for eighteen representative research cluster descriptions when being considered independent of mission requirements. It remains, then, for the planner to examine the influence of these data management concepts on mission planning activities, when deriving consolidated system requirements for mixed groupings of experiments. Any final systems analysis will include performing in-depth tradeoffs among research data handling alternatives based on a selection of specific candidate experiment groupings and the knowledge of specific missions and spacecraft proposed. Broad data system considerations leading up to this point in data management mission planning are discussed below.

The relationship between experiments and experiment data management may be addressed by first considering the transfer of experiment data between major elements of the manned space facility and its associated programs, and then considering the acquisition, processing, and distribution of experiment data being generated within each major element.

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*Information Management System Study, Space Station Program, Volumes I and II, Federal Systems Division, IBM, April 1970, IBM Report No. 70-K34-001.

The major elements to be included in considering an Earth-orbital space program include the use of a Space Station, shuttle, attached experiment modules, and free-flying experiment modules; and their associated ground data-handling facilities. Separate data-relay satellite system (DRSS) and space shuttle programs will provide the necessary support in communications, the delivery of major elements to orbit, and logistics support for expendables, and the return of physical data and samples to Earth.

In terms of the above major elements, the data management system (DMS) requirements for communications support must define the following for ground station and DRSS use. These requirements have significant effect on the total mission plan, and each of the items listed must be given consideration in the conceptual planning stage:

A. Proposed date of launch.

B. Duration of the mission.

C. Hours or days of the required support.

D. Ground stations and facilities desired for support.

E. Spacecraft flight events that affect tracking and telemetry; e.g., start and stop times of burns; start times, directions, and purposes of attitude maneuvers; beacon, transponder and telemetry transmitter on and off times; and the times and description of vehicle-separation events.

F. The telemetry and tracking systems on the spacecraft, including type and location of the antennas.

G. The telemetry link parameters. These parameters are needed to plan station and satellite configurations for tracking, receiving, recording processing, and transmitting data from each link.

H. The coverage requirements for each link; e.g., intervals of telemetry and track coverage from launch time and the specific flight events of the mission; definition of data requirements; the accuracy desired for position and velocity determination; and the desired signal level above threshold, if applicable.

I. The requirements for real-time or near real-time data and commands, the formats required, and the destination of the real-time remote data.

J. The requirements for recorded data, including the spacecraft-generated data, such as timing. As applicable, a description of the data recording form and formats should be included, the times and length of recording, the desired number of copies or duplicates, and a distribution list of recipients.

K. Special requirements for test support, simulations, reports, or unusual network support described in detail.

L. The time frame proposed for supplying final trajectory tapes, gain contour data for antennas, telemetry formats, and simulation data tapes and scripts.

5.5.1 DMS Function Analysis

The following classical data management functions are not so clearly defined when viewed at lower functional levels where one sees not only the wide variety of data forms involved but also the variety of operations, controls, timing, and user information needs.

A. Acquisition

B. Routing and flow control

C. Storage

D. Processing

E. Disposition

These second-level parameters are the most meaningful and are the subject of current efforts to provide further definition in such areas as:

A. Film or video for image data acquisition.

B. Special onboard image processing for quick-look evaluation.

C. Logistics impacts of data form.

D. Communications impact of data form.

E. Real-time data requirements.

F. Image processing requirements (enhancement, correction, and reduction).

5.5.1.1 Acquisition

Since a very large share of the scientific data generated and sensed onboard the spacecraft will be in the form of images, an early decision must be reached on whether to use photographic film or high-resolution video cameras as the medium by which image data are collected. The selection will be based on criteria, such as that shown in Table 5-7. None of the separate factors

Table 5-7

CRITERIA FOR SELECTION OF FILM OR VIDICON FOR DATA TRANSFER

	Resolution	Spectral Response	Response to Low Light Levels	Acquisition Manhours	Review and Evaluation Potential	Real-Time Response Potential	System Fidelity Including Recording	Onboard Processing and Reduction Potential
Film Camera	High	Broad Selective	Fair	High	Poor	None	Excellent	None
Video Camera	Medium	Medium Relatively Fixed	Excellent	Low	Excellent	High	Good to Fair	Good

shown constitutes a decisive quality in itself, but it must be considered in the context of experiment objectives and the more-practical operating requirements, including: .

A. Resolution required (or acceptable).
B. Mission impacts of long exposure times.
C. Required control visibility.
D. Evaluation methods and timelines.
E. Encountered environments.
F. Local or free-flyer operation.
G. Logistics requirements for returning data to Earth.
H. Principal investigator involvement.

Results from previous studies* indicate the the resolution of return-beam vidicon tubes can be improved from 100 lp/mm in 1970 to at least 150 lp/mm in 1975. This is true for both the 1-by 1-inch and the 2-by 2-inch. formats,

*Sensor Definition Study in Support of Unified Space Applications Mission (USAM) IBM Report, Feb. 1968, Contract No. NAS 5-10436, GSFC.

as illustrated in Figure 5-34. The total line-pair capability of the tubes (without lenses) shows an increase from 2,500 line-pairs for the 1- by 1-in. tube to 7,500 and 10,000 line-pairs for the 2- by 2-inch and 4- by 4-inch tubes.

The resolution of vidicons with lenses is shown in Figure 5-35. At a contrast ratio of 1.3:1, the resolution of the 2- by 2-in. vidicon with lenses in 110 lp/mm (6,050 total lines), and that of the 4- by 4-in. vidicon is 88 lp/mm (8,800 total lines).

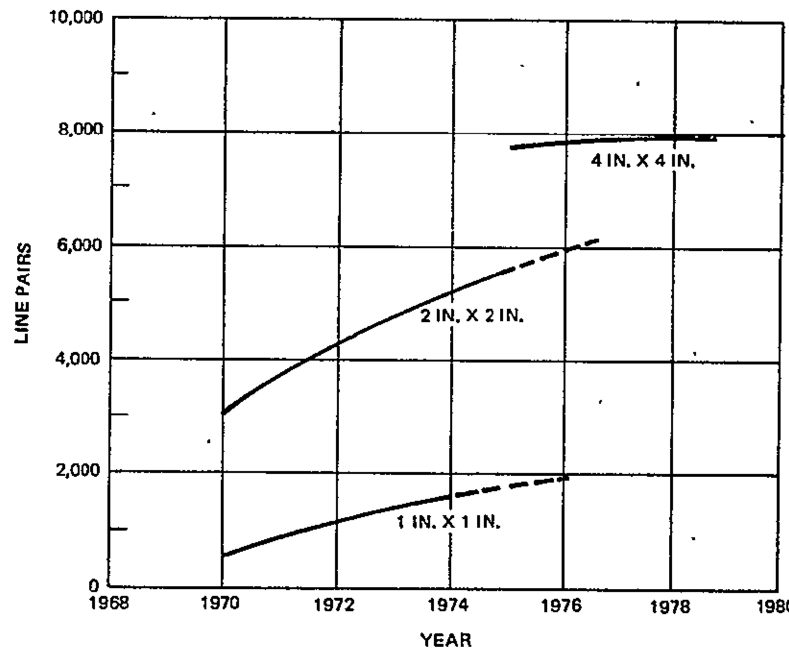


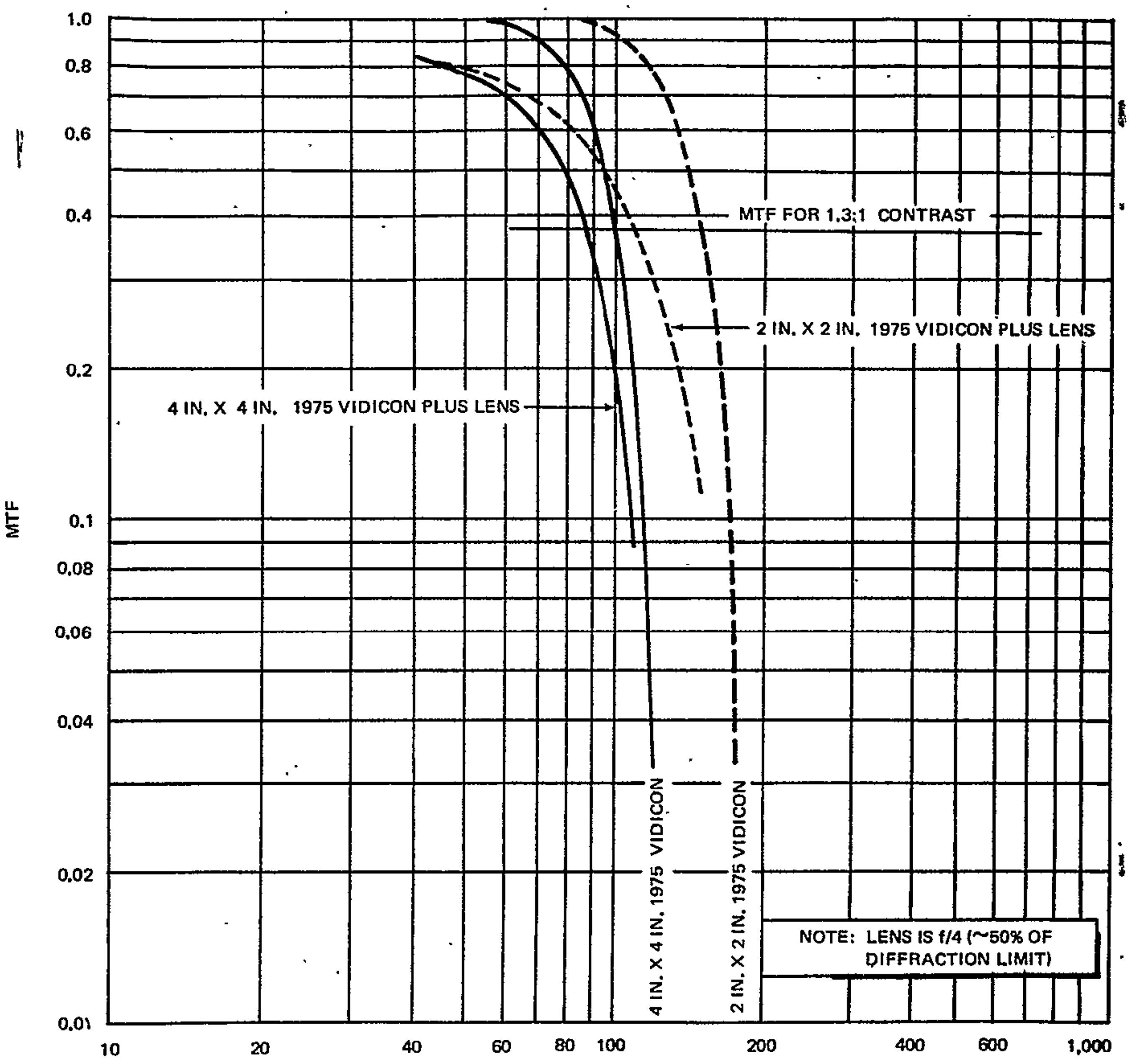
Figure 5-34. Future Trends in TV Camera Total Line Pairs*

5.5.1.2 Data Routing and Flow Control

Acquired data will be used to fulfill a variety of operational and evaluation functions. Among these are:

A. Target acquisition displays.
B. Pointing error display.
C. Scientific data display.
E. Equipment status and mode displays.
F. Control computation.

*Sensor Definition Study in Support of Unified Space Applications Mission (USAM) IBM Report, Feb. 1968, Contract No. NAS 5-10436, GSFC.



*SENSOR DEFINITION STUDY IN SUPPORT OF UNIFIED SPACE APPLICATIONS MISSION, NASA CONTRACT NAS 5-10436, INTERNATIONAL BUSINESS MACHINES CORPORATION, FEB 1968.

Figure 5-35. Modulation Transfer Function of Near-Future (1975) Vidicons*

Functional implementation of any or all of these requirements strongly depends on the rate at which data are generated and the degree to which monitoring and control are required.

5.5.1.3 Storage

All functions performed on or with data require storage at one or more points within the data-flow system, and there is a requirement for a hierarchy of onboard storage locations to hold data or queue data bit streams for varying periods of time from a few seconds to permanent storage. Storage requirements are applicable for all data forms - film, electronic, and sample data. Film and samples will require special storage facilities that provide radiation shielding, refrigeration, and cryogenic freezing. Experiment timelining and logistics schedules determine the size of the storage capability, whereas the operation tasks and required management determine its architecture.

5.5.1.4 Processing

The operational aspects of converting or transforming data to enhance its information content has not been explored in this study except on an individual basis where data quantities were excessive (i.e., imagery and spectral types). It is possible, however, to look at processing on a less detailed level to identify categories of requirements for allocation to onboard or ground facilities. Categories to be considered include:

A. Processing for display.
B. Processing for evaluation.
C. Processing of control.
D. Processing for experiment management.

Special processing requirements include the option of onboard chemical processing of photographic film and the option of onboard processing of image data. Significant problems are encountered with large-scale implementation of this type of processing in terms of chemical fluid handling in a zero-gravity environment and also for computer sizing and logistics space and weight requirements. Real time user requirements will necessitate some degree of image processing.

5.5.2 Experiment Data Management

The development of a space-experiment data management system requires careful consideration to satisfy the needs of the experiment data requirements. A representative approach for coordinated research program and data management system development is illustrated in Figure 5-36. The process begins with a broad definition of a candidate research program, where groupings of research instrumentation guidelines, and constraints such as the role of the space vehicle crew and principal investigators are established. This is followed by a more-detailed technical analysis leading to a definition of the experiment program requirements, including the allocation of experiments to particular vehicles. The research program requirements are then analyzed to determine interacting requirements that the measurements impose on data management system requirements. A candidate data management system is postulated, and its capabilities are defined and tested against the previously stated experiment program requirements. If these requirements are considered satisfied, the data management system and experiment program hardware and software developments may proceed on a parallel basis. If the program requirements are not completely satisfied, or as requirements reach a more definitive level, iterations of the data management concept and capabilities are executed to include data management system requirements analysis, research cluster requirements analysis, and experiment definition, until a mutually compatible set of experimentation requirements and data management system capabilities is established.

While the process described was not fully applied to the broad study program, due to the need for more definitive experiment specifications, most of the data management steps are evident. Referring to the first three blocks in Figure 5-36, the procedures followed resulted in the analysis of general data system requirements for each of the research clusters. The selection of 18 research cluster data examples for further analysis produced definitive estimates of system concepts and requirements representing the expected magnitude of data management in the six scientific and technology disciplines. Any further analysis is dependent upon having specific missions and space

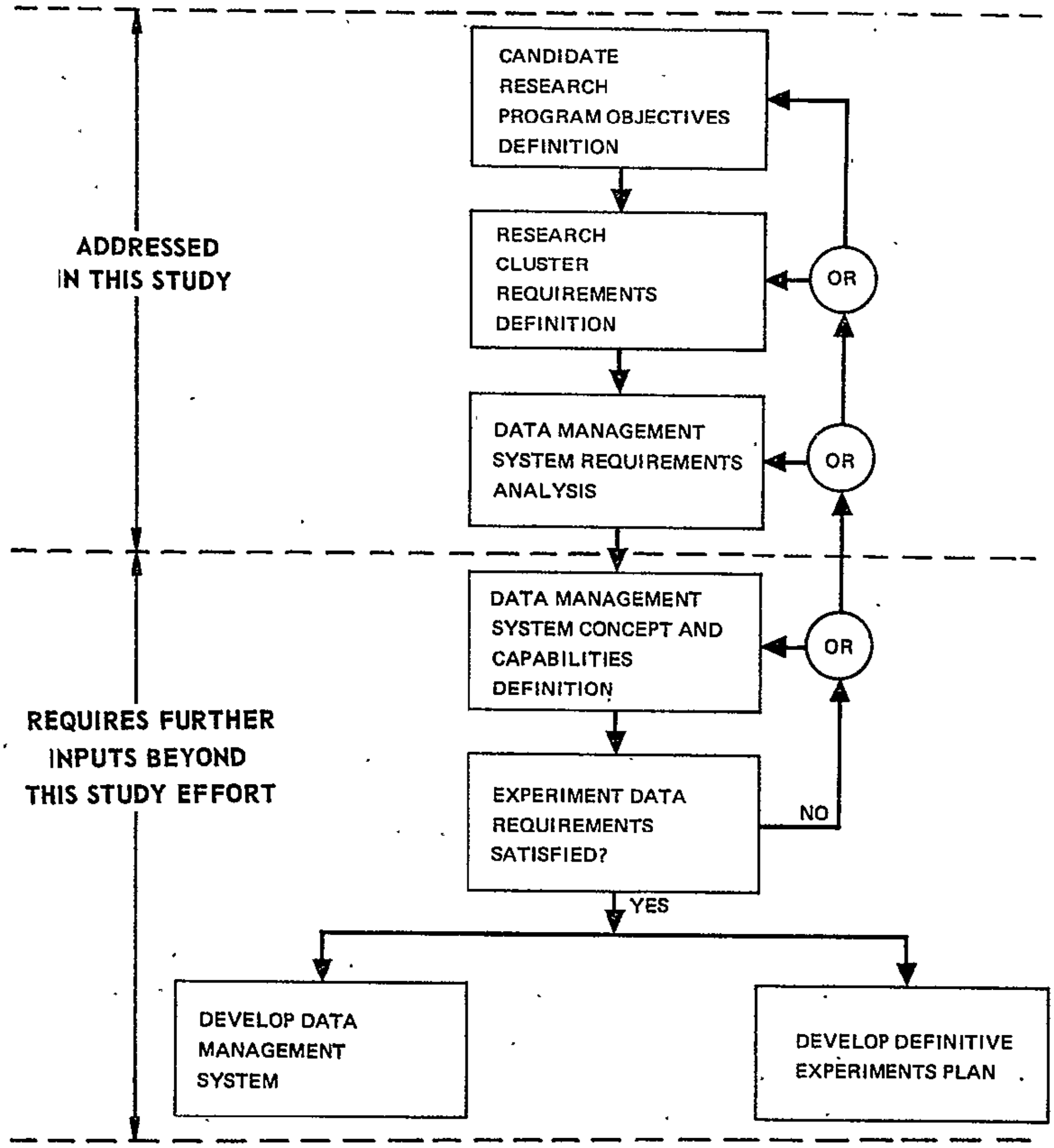


Figure 5-36. Experiment Program—Data Management System (DMS) Development

vehicles proposed. Referring to Figure 5-36, several of the latter steps (see Fig. 5-36) were not accomplished within the scope of the study. However, the following paragraphs explain the general development process involved with examples included whenever appropriate.

5.5.2.1 Experiment Data Forms and Data Flow

Experiment data will be transmitted between major space elements in any one or combinations of several forms:

A. Electronic data are the data that are transformed into electrical signals for either hardwire or radio-frequency carrier transmission. Electronic data includes analog, digital, discrete, audio, and video signals.

B. Physical data consists of electronic data that have been recorded on photographic film or magnetic tape, and must be physically transferred between spacecraft elements.

C. Commands are analog or digital signals that are transmitted between spacecraft elements by either hardwire or by radio-frequency carrier, and used to control experiments at the receiving end.

D. Samples are biological specimens and materials that have been exposed to the space environment for analysis, either onboard the spacecraft, or which are transferred to ground-based laboratories by logistics vehicles for subsequent analysis.

A representative overall flow of experiment data between major spacecraft and support elements is illustrated in Figure 5-37. The spaceborne data management system is the primary interface between experiments and the space crew members, and between orbiting vehicles and ground facilities. The space vehicle may transmit wideband electronic data to the ground and receive commands and data from the ground on a practically continuous basis through the use of a Data Relay Satellite System (DRSS). Alternatively, the spacecraft may communicate directly with the central ground facility on an aperiodic basis when the ground facility is within view. Other ground stations (not shown) may be used to supplement the central ground facility to gain additional communication time. Experiment data may also be stored on photographic film or magnetic tape for subsequent retrieval or for return to Earth.

The free-flying experiment modules will communicate primarily with a Space Station or a shuttle logistics vehicle through RF carriers. Physical data may

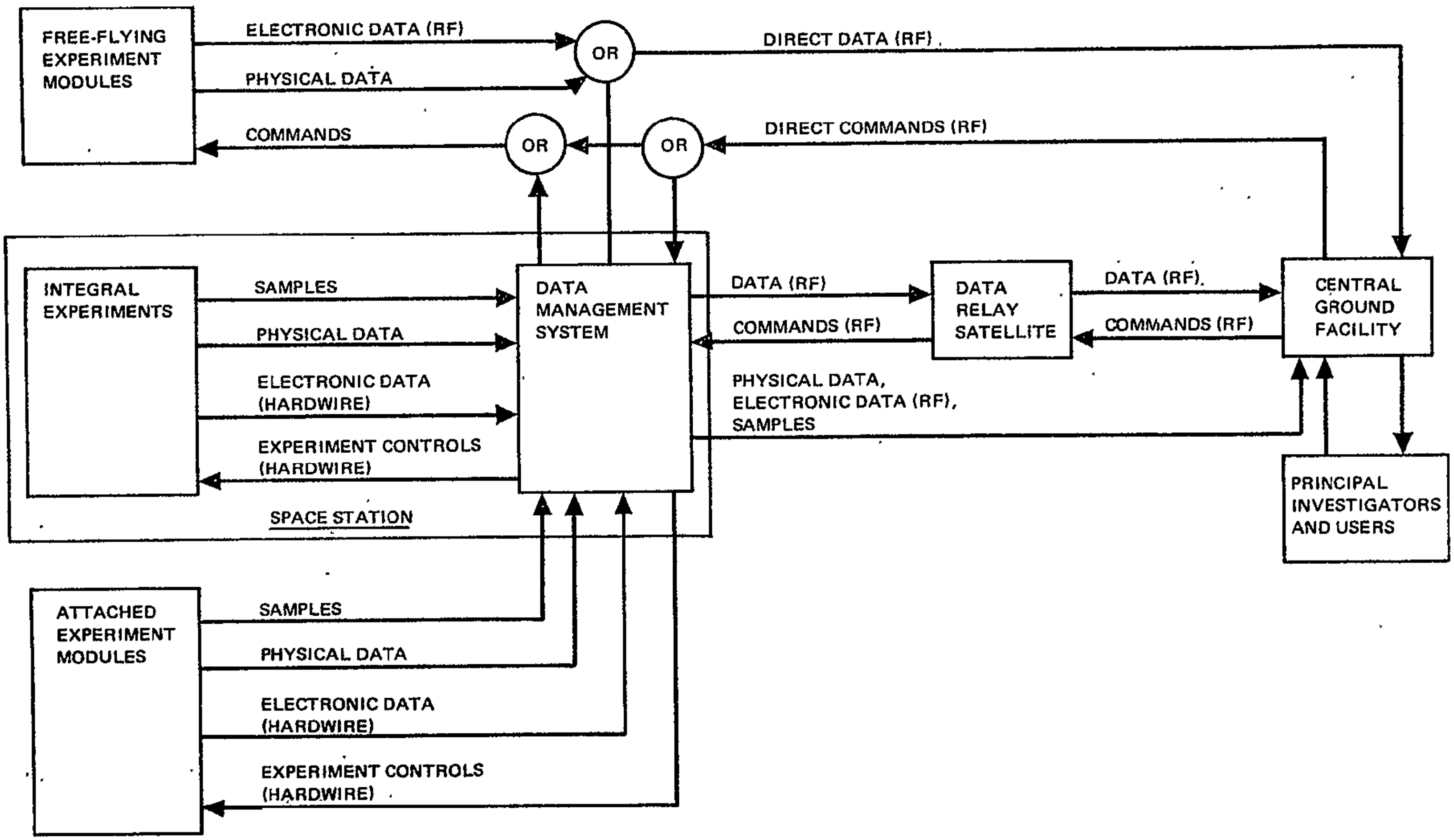


Figure 5-37. Representative Experiment Data Management Data Flow

be transferred between the free-flying modules and the Space Station or shuttle, when the free-flying experiment modules are docked for periodic servicing.

Alternative links for direct communication between the free-flying experiment module and the ground station may be used either to supplement the Space Station or shuttle communications capability, or for operation independent from the support facility. For example, free-flying astronomy experiment modules operating in a synchronous orbit could communicate directly with the ground station on a continuous basis without the necessity of a Space Station or Data Relay Satellite System.

The spacecraft Data Management System services the integral experiments and the experiments in attached modules in similar manners. Experiment data acquired electronically may be processed onboard, and the processed data may be either transmitted to ground stations via RF carrier or recorded on magnetic tape for physical return to Earth. Experiment photographs may be converted to electronic data, analyzed onboard, or transmitted to ground stations for further analysis. Similarly, samples may be analyzed onboard, and the results may be either stored onboard or transmitted to ground stations. Alternatively, samples may be returned to Earth for analysis.

A. Space Station, Shuttle, and Attached Module Experiment Data Management. The Space Station and shuttle data management systems can be expected to provide for the acquisition and distribution of data from experiments and to control experiments within the Space Station, shuttle, and free-flying and attached experiment modules, as indicated in Figure 5-38. Typically, in the case of a Space Station, the DMS will perform the following support functions:

   1. Acquire analog, digital, discrete, and video signals from experiment sensors, whose outputs are in the form of electrical signals.
   2. Provide signals to control experiments, such as sensor pointing, mode switching, and photographic film transport.
   3. Provide signals to control experiment stimuli generators for checkout and calibration purposes.

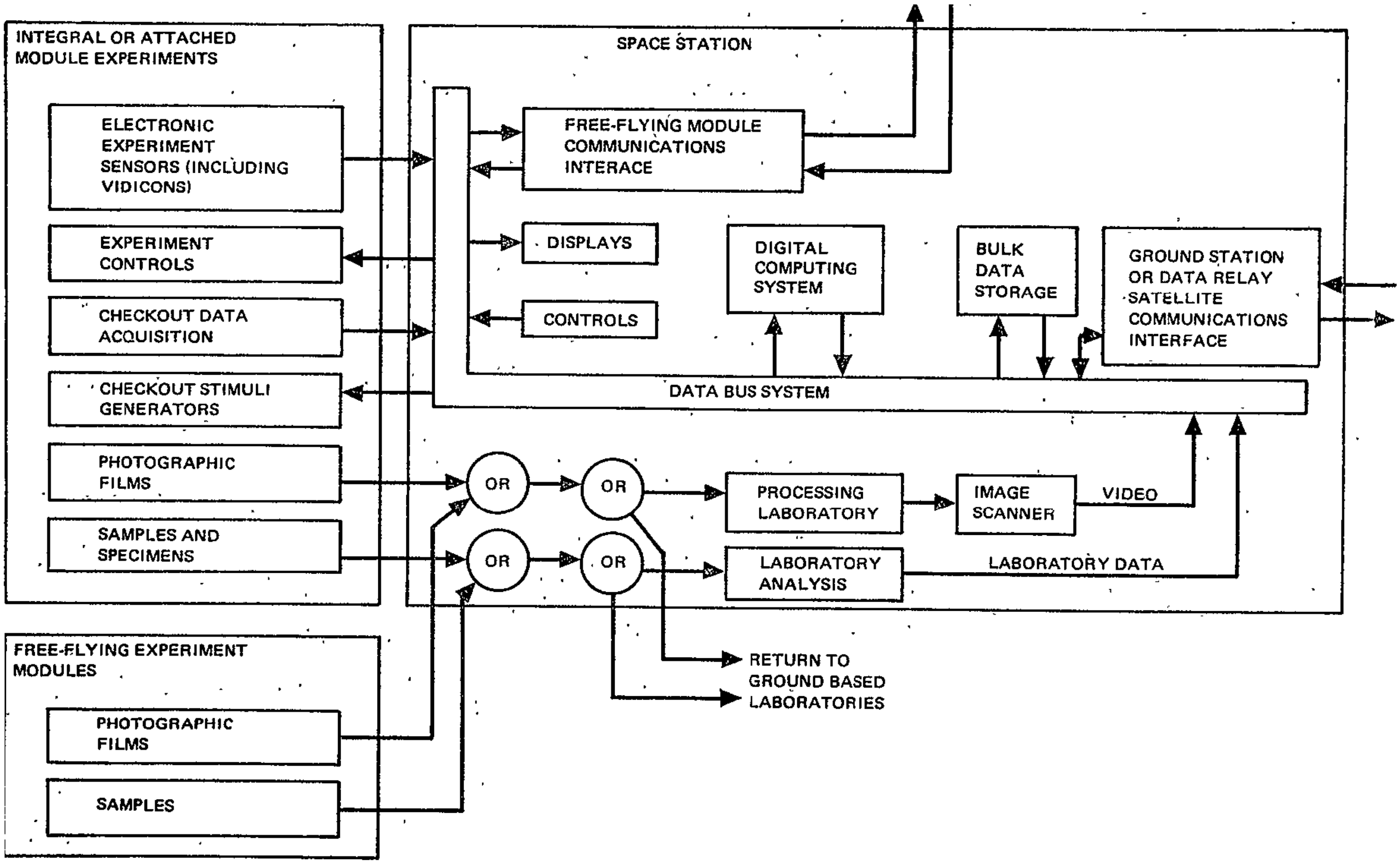


Figure 5-38. Representative Space Station Experiment Data Management Data Flow

4. Acquire experiment checkout data and determine the operational status of experiments.

5. Process selected photographic films, either for onboard experiment analysis, or to monitor the experiment for proper operation.

6. Analyze photographic images for characteristics peculiar to the particular experiment.

7. Process data obtained from laboratory analyses of material samples and specimens.

8. Store bulk experiment data in analog, digital, or video format for subsequent onboard analysis or transmission to ground stations.

9. Transmit experiment data to ground stations, either via a Data Relay Satellite System or directly to one or more ground stations.

10. Provide experiment-to-astronaut crew interfaces through control and display panels.

11. Provide a digital computing capability for experiment management and control, special experiment data analyses, such as image processing, statistical and trend analyses, and correlation with other data.

12. Receive data and instructions from principal investigators and other ground station personnel, as necessary in the conduct of the experiments.

B. Free-Flying Module Experiment Data Management. The free-flying module experiment data management system provides for the remote acquisition and distribution of data from experiments, and control of experiments within the free-flying module as indicated in Figure 5-39. Typically, the free-flying experiment module will have experiment data management capabilities slightly different from those of the Space Station. It will be able to:

1. Acquire analog, digital, discrete and video signals from experiment sensors.

2. Provide signals to control experiments.

3. Control the experiment module orientation for experiment pointing.

4. Acquire checkout data and determine the operational status of experiments.

5. Transmit experiment data to either the Space Station or directly to ground stations via an RF link.

6. Receive commands from either the Space Station or directly from ground stations via the RF link.

As indicated in the figure, photographic films and samples may be transferred to the Space Station or shuttle when docked. The films and samples may be further analyzed onboard the manned vehicle, and thus require the services of the Space Station or shuttle Data Management System, or be transported to

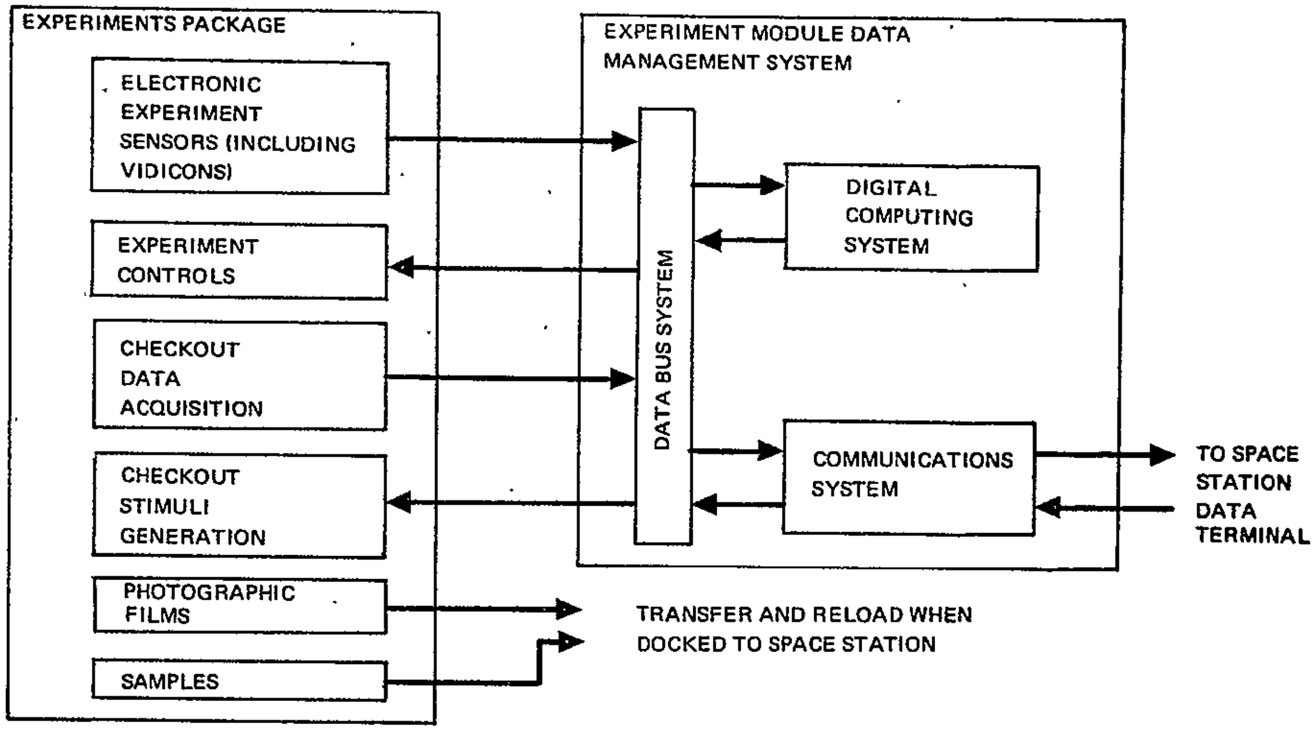


Figure 5-39. Representative Free-Flying Module Experiment Data Management-Data Flow

ground for future analysis.

5.5.2.2 Requirements Analysis

Numerous trade studies must usually be performed to configure a feasible Data Management System for the research program. The ability to perform meaningful trades, however, is contingent upon the successful completion of a data requirements analysis. Although this analysis is primarily intended for use in configuring the Data Management System, the requirements also can influence the selection of an experiment payload grouping since total data flow can constrain experiment operation. This makes the requirements analysis an iterative process in that requirements for all research disciplines are analyzed and the total requirements collected and submitted as an input into the candidate research program selection process. The selected research cluster grouping then modifies the total data management requirements by the effect of either research task deletions or data system expansion.

The techniques used in the planning analysis performed in this study are shown in Figure 5-40, to illustrate the representative data management system requirements definition process for the space facility, grouped experiment configurations, associated ground facilities, and interfaces with other programs. The definition of experiment data management requirements uses inputs from both programmatic and individual experiment requirements definitions The programmatic requirements from the candidate experiment payload definition contributes to the allocation of each experiment into a particular orbiting element, the general time period when the experiment is to be performed, and the overall guidelines and constraints that affect experiment data management system requirements. The individual research cluster data management requirements provide information necessary to identify the onboard and ground data management system functions; such as data acquisition, data processing, storage, displays and controls, communications requirements, and typical experiment time-line activity definitions. Consideration of both the candidate research program definition and individual experimentation data management requirements should result in a consolidated set of requirements for each orbiting element and the associated ground support systems. Some detailed experiment time-line analyses and scheduling are required to verify the design requirements. Unless constrained by experiment requirements, implementation schedules may be adjusted to reduce peak demands on the data management system. Finally, the data management requirements routinely produced by other vehicle subsystems, such as guidance, navigation, attitude control, environmental control and life support, and communications, must be merged with the research payload data management requirements to define the total data management system requirements for each facility. This consolidated support requirement would then be used to specify the final vehicle data management system specifications for detailed design purposes.

Basic issues which remain, and which were not within the study scope but are none-the-less critical to the complete definition of Data Management Systems are as follows: (1) allocation of experiments to the Space Station, shuttle or particular free-flying or attached experiment modules; (2) definition of the role of the space crew and principal investigators in conducting experiments

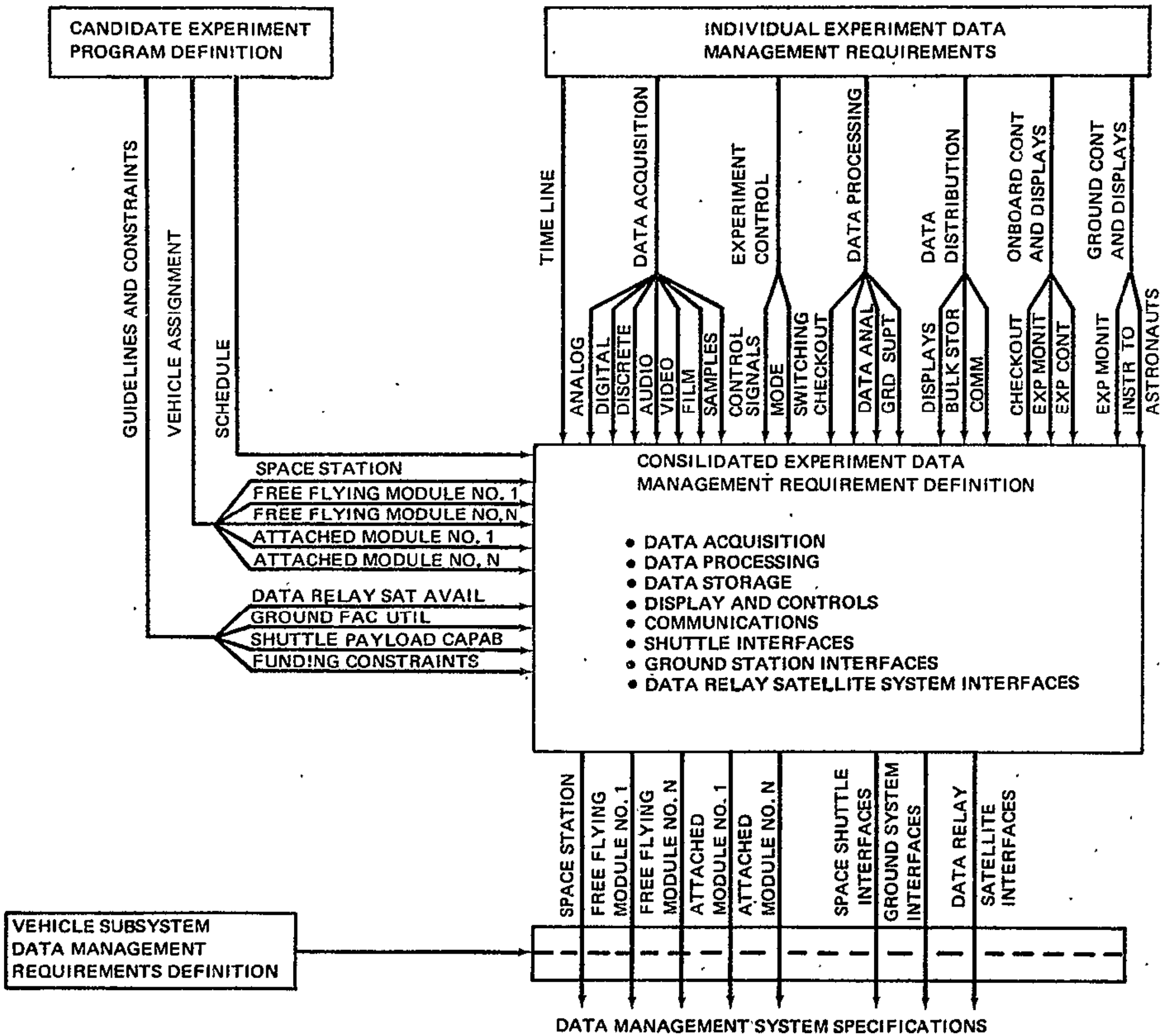


Figure 5-40. Data Management System Definition Process

and in analyzing experiment data; (3) definition of experiment schedule constraints and representative time-line operational profiles; (4) definition of image sensor types; (5) definition of experiment to data management system interfaces and onboard support requirements.

5.5.2.3 Sample Operations Analysis of DMS Requirements

To demonstrate that the operational definitions of experiments could be useful in completing the DMS requirements, two research clusters were chosen, Biomedical and Earth Observations. Biomedical was chosen because of its high priority and crew safety aspects and Earth Observations because of its usefulness to current problems in food production and pollution.

The approach for the biomedical example was to take each biomedical activity, examine it for the time required on various days of a 45-day repeat cycle, and then to select a specific day and prepare a detailed schedule for a 24-hour period, assigning the required tests to the crew (Figure 5-41). (Day No. 2 was selected because it appeared to be one of the busier days). The experiment identification is shown below the time-line, i.e., 1-BM-4, 1-BM-5, and so on.

In the course of preparing this schedule from the requirements in the research cluster definitions, a number of problems became evident:

A. Scheduling problems. Review of crew tasks (crew matrix, Appendix C) on cardiovascular and vestibular functions reveals a daily test requirement for two subjects for 103 minutes. Other tasks indicate three subjects to be tested for 335 minutes and one subject for 440 minutes. If taken sequentially, these tests would exceed the crew availability time in a 24-hour period. The more practical approach calls for careful scheduling of the crew over longer periods, as necessary.

B. Excessive crew requirements. An attempt was made to divide the work among 12 crew members working in three 8-hour shifts; it became evident, however, that this schedule would have to be increased so the thirteenth and fourteenth men were added to hold the work load to about 10 hours for any one man. Additional crew members would also be required to perform the normal spacecraft housekeeping functions, not to mention scientific experiments that would be expected to be included.

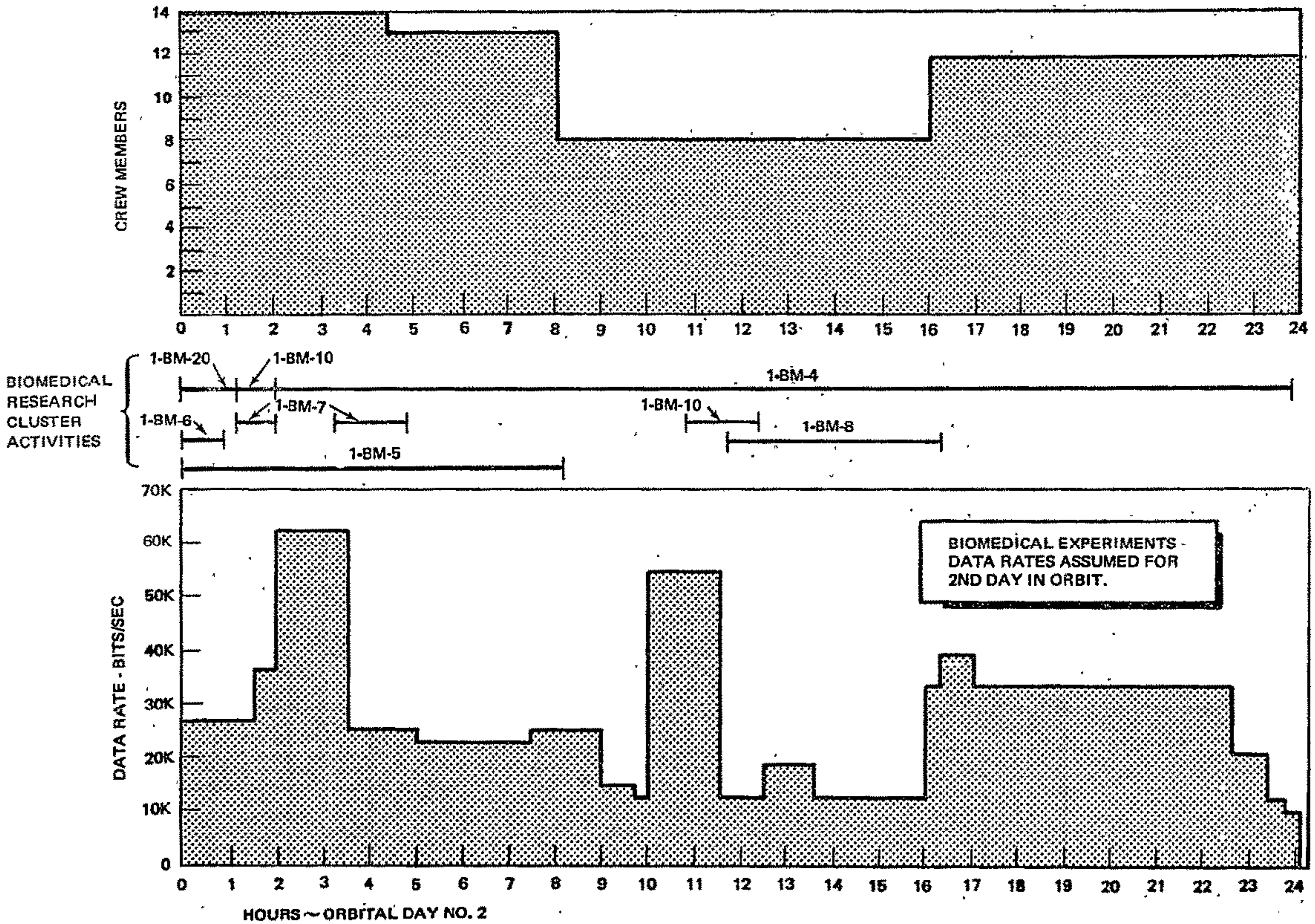


Figure 5-41. Data Rate Schedule-Biomedical

C. Crew assignment. To divide the various experiments among the crew members over three shifts, it became necessary to assume that any man could perform any task, including interpretation of data, which is the function of an M.D. crewman. It is evident, however, that one M.D. crewman would not be sufficient for three full shifts performing biomedical experiments.

A data-rate time-line was derived for the same day. It was based on given data requirements or estimates of data rates required for the various measurements indicated. It was expected that the data-rate envelope peaks could be shown to be an order of magnitude greater than the average data-rate requirements, and detailed analyses of the steps in the first experiments were examined. On the basis of this analysis, it appeared that the data could be reduced by only about 50 percent and not by an order of magnitude.

The conclusions from the analysis are than a 12-man crew cannot perform all of the required biomedical experiments as required in 45 days; and that, according to time-line indications, data rates on the order of 40 kilobits per second or 10^9 bits per day are the maximum data rates, even if 14 men could be made available for experiment purposes.

The experiments must be reevaluated with the view of eliminating those activities that offer little promise of any significantly unique results, scheduling over a longer period of time; and reducing the data acquisition period to a fraction of the experiment time. To solve the crew loading problem, some of the crew function can be automated.

The approach taken for Earth Observations was to evaluate the cluster description to determine whether any constraint was apparent that would affect DMS requirements. It appears that target availability may limit the taking of data. To demonstrate this problem, fourteen truth sites from Research Cluster 6-A/F-1 were selected. Using a 250-mile orbit, a 52.1° inclination, and various look angles from the space platform to the target, coverage times were determined that represent the target acquisition geometry of the 22 sensors used for Earth Observations sensing. The results of the analysis are plotted in Figure 5-42*. The two curves that are plotted in their entirety

*IBM Computer Program STACOV, MSFC New Technology III-6-603-110.

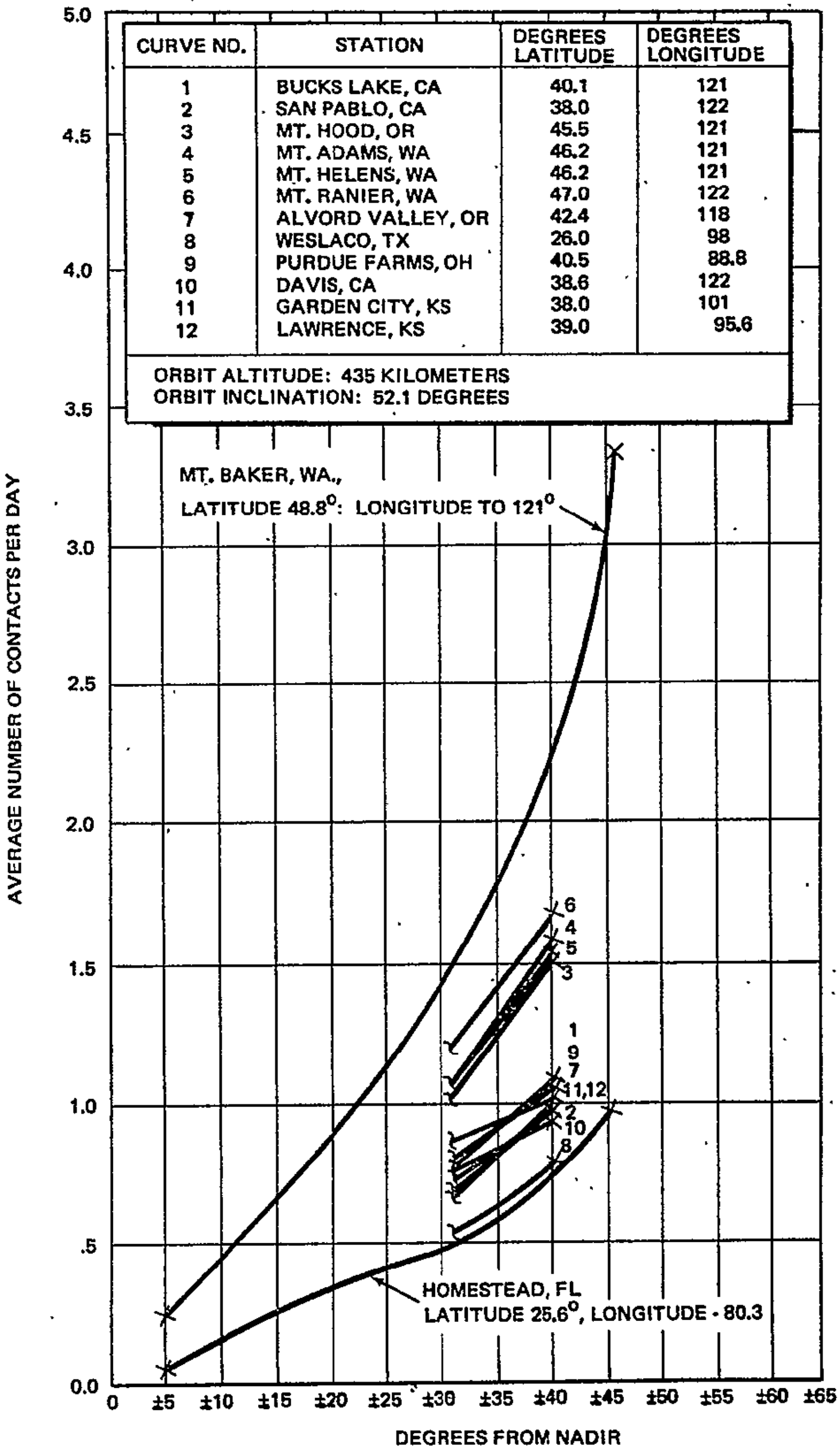


Figure 5-42. Target Contacts at Various Look Angles

represent the upper and lower bounds of all the sites considered with the remaining 12 locations plotted as two points for visual simplicity. This data indicates only contacts, not duration of contact. The average durations of contact are shown in Figure 5-43, as a function of look angle.

Not shown on the curve are two other considerations that affect the generation of data: sun angle, and cloud cover. In general, the sun angle constraint limits the acquisition of data from most of the 22 sensors to approximately one out of six contacts, since a suitable sun angle is NADIR ± 30 degrees. Cloud cover also limits the target opportunity so that in most agricultural areas in the United States, visible target opportunities would be reduced approximately 60 percent.

To demonstrate the effect of these constraints on data management requirements, consider the daily data outputting time of the fourteen targets in Figure 5-42. Taking an average sensor look angle of ± 15 degrees, the average target contact per day is found to be approximately 0.5 contacts. Multiplying by the 14 targets, we average 7 targets per day. Applying the sun angle approximations we have 7 x 1/6 (or 7/6) of a target.

Considering the cloud cover estimate, we are left with an average of 7/6 x 60 percent, or 0.7 of a target per day. From Figure 5-43, the average time per contact for a ± 15-degree look angle is 22 seconds. The data generating time, exclusive of calibration and checkout, is 15.4 seconds. This, of course, does not become the total data rate of 6-A/F-1 since this analysis addressed only the truth sites and not the operational targets. Another problem with the analysis is that, for some required ground resolutions, a look angle of 15 degrees is too large. The preceding analysis only attempts to demonstrate that target availability will be a continual constraint on the DMS and that a similar analysis must be performed for all selected experiments using Earth targets and must include operational timelines. This conclusion was reached because of the limits imposed on target availability by:

A. Actual duration of time over target from a 250-mile orbit at a 50-degree inclination.

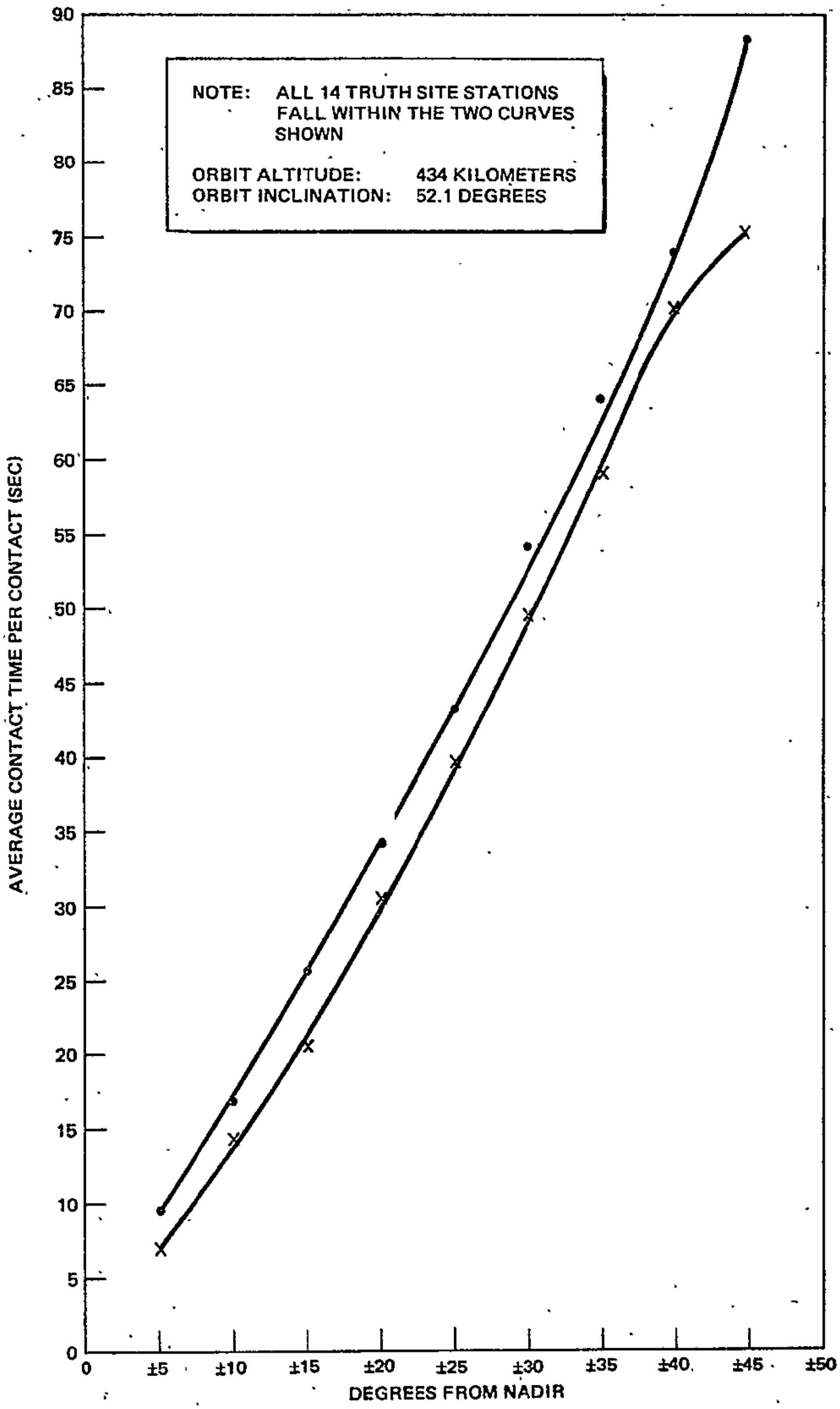


Figure 5-43. Average Contact Time per Contact at Various Look Angles

B. Constraints imposed by a suitable run angle at the time of observation ($\pm$ 30 degrees from NADIR).

C. Reduction of target availability by cloud cover (estimated at 60 percent).

5.5.2.4 Communications

The return of large quantities of electronic data to the ground via an RF communication link imposes some severe restraints on the design elements in the communication link. The first basic question to be answered is how complete (or nearly continuous) the coverage must be over a normal 24-hour period. The present Manned Space Flight Network, consisting of 11 ground stations plus a new station at Santiago, Chile, gives 425 minutes of direct line-of-sight contact between the spacecraft and the ground station during an average 24-hour period; for a spacecraft launched at a 50-degree inclination, in a 235-mile circular orbit with coverage gaps up to 133 minutes. Between now and the operational period of the Space Station (1980's), many ground stations are expected to be closed down since identified interim programs do not require them. Two possible alternatives for transmission of high data rates from the spacecraft to ground will be compared in the following discussion.

A. A reduced MSFC network with direct communications limited to 100 to 300 min per day for an average 24-hour period. Onboard storage capability provided to store data during the gap intervals and to dump data at very high data rates while a space vehicle is over any one ground station.

B. Continuous communication via a Data Relay Satellite Network.

The first alternative is certainly the least costly by virtue of using existing sites and equipment. Attendant factors in using the MSFC are that attenuation losses are much less for spacecraft-to-ground communications, resulting in less stringent RF component design specifications (particularly for the spacecraft antenna). Bulk storage with high-speed playback capability must be added to the spacecraft.

Transmitted data rates ranging from 10^{10} to 10^{12} bits per day (estimated to be the mission data range) are compared against transmission rates, as shown in Figure 5-44. Curves are plotted for 100, 212, and 300 min per day of communi-

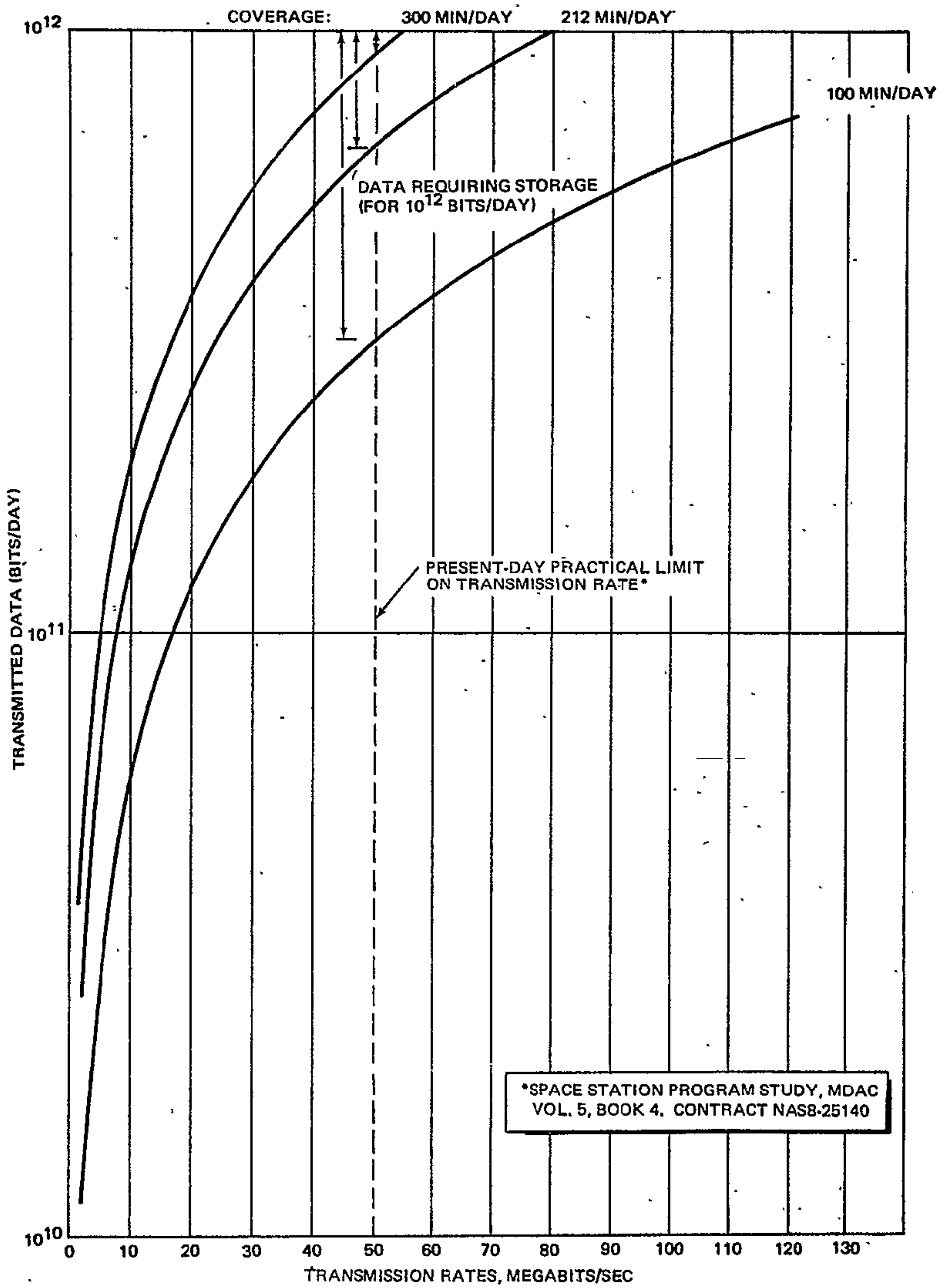


Figure 5-44. Transmission and Storage for Various Transmission Rates and Coverage

cations contact, respectively.

For a given transmission rate, the amount of data below the curve can be transmitted during a 24-hour period. The data represented by the ordinate above the curve must be recorded on tape. It can be seen that data quantities on the order of 10^{12} bits per day require storage, since adequate transmission rates greater than 50 Megabits-per-sec are not feasible at present.

The amount of required data storage in bits per day is plotted in Figure 5-45. Storage requirements are plotted for 10^{12} bits per day with 10 and 50 Megabit-per-sec transmission rates, and for 10^{11} bits per day with 2 and 10 Megabit-per-sec transmission rates. The storage requirement for 10^{12} bits/day at the 50 Mbps rate may be eliminated if the communication contact time can be extended to 340 minutes per day.

The cost of storage in terms of the number of tapes consumed over a period of time is shown in Figure 5-46. This information is given for data rates of 10^{12} and 10^{11} bits per day and for transmission rates and coverage given in Figure 5-45. A data capacity of 10^{10} bits per tape is assumed, and the time was extended to 3 months - the assumed period between logistic flights.

The second alternative, a Data-Relay Satellite network, has received considerable attention from study efforts during the last 8 years. The chief advantage of a Data-Relay Satellite network is continuous coverage in real time, without MSFN support. If the present NASA plans of closing down most overseas stations between now and the operational period of shuttles and a large Space Station (1980's), is carried out, the only real alternative left would be to use a DRSS.

Some of the disadvantages of the DRSS approach are:

A. The initial (or nonrecurring) cost of a two-DRSS network is estimated to be 83 million dollars or 103 million for a three-DRSS network.

B. Additional RF hardware configuration costs necessary to reduce the large space losses between the spacecraft and DRSS.

C. Requirements for acquisition and tracking between high-gain antennas on the spacecraft and DRSS.

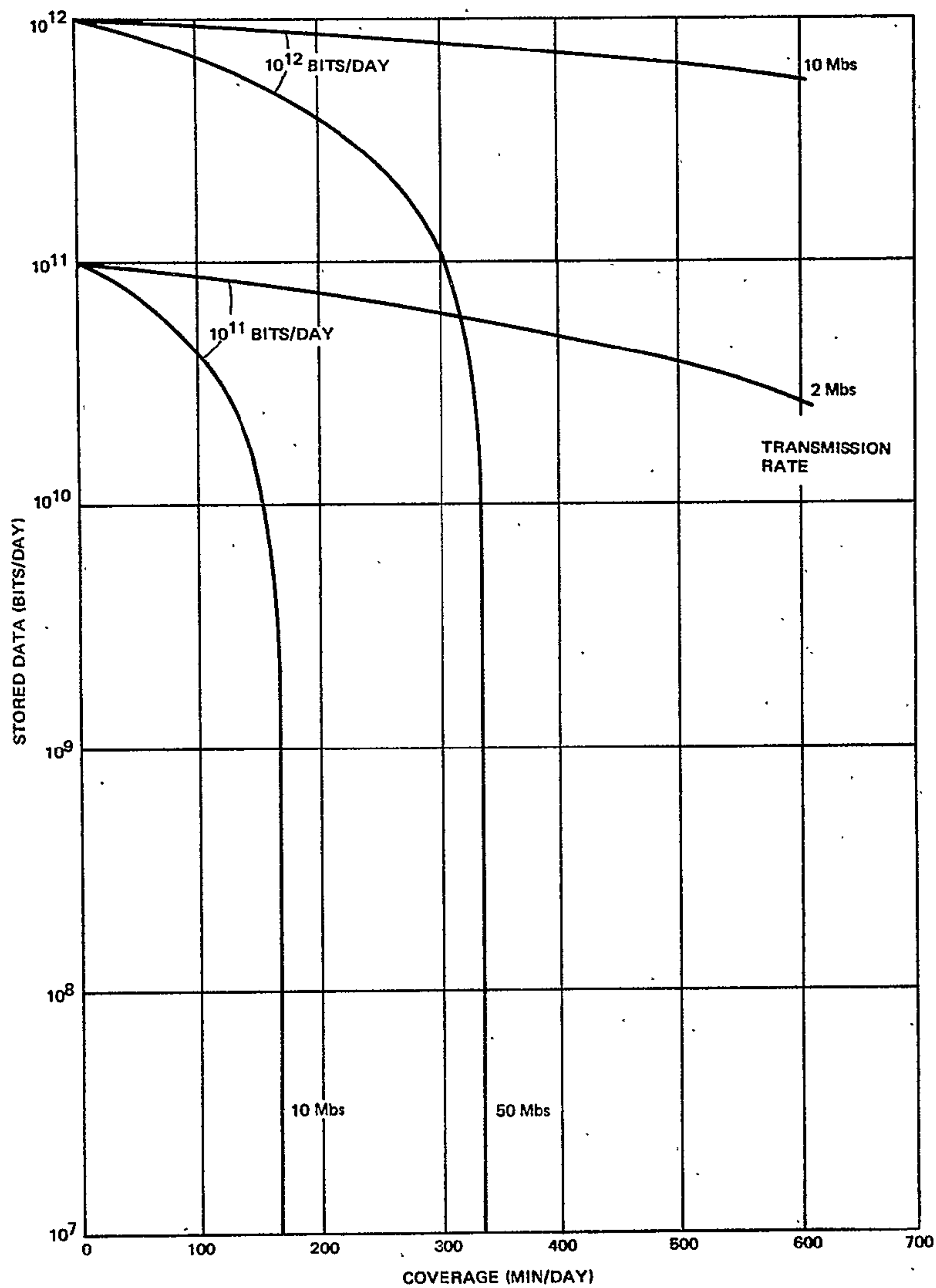


Figure 5-45. Amount of Stored Data in Bits Per Day for Different Transmission Rates and Daily Quantities of Data

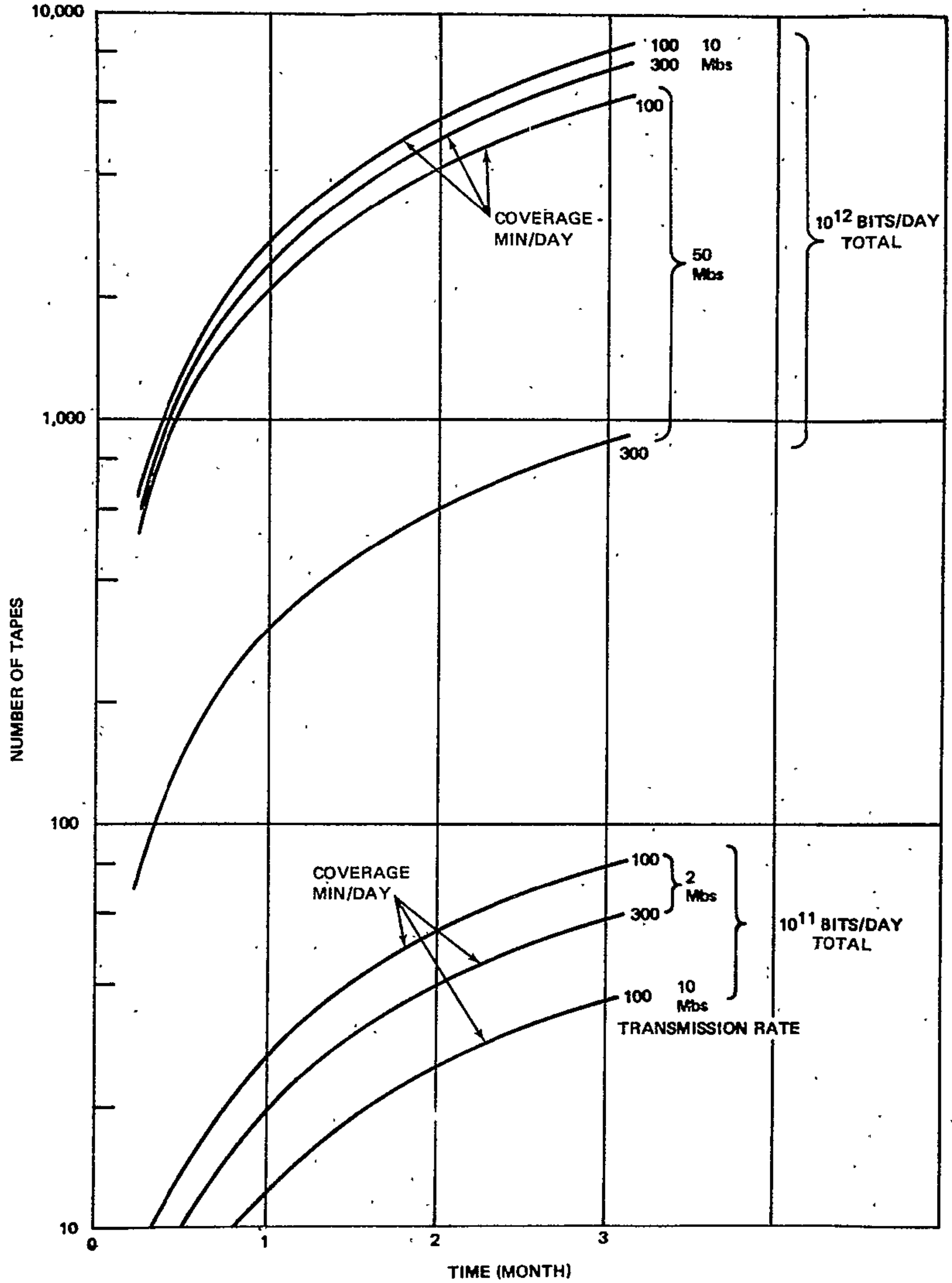


Figure 5-46. Number of Tapes Consumed Over a Period of Time for Coverage and Data Transmission Rates Given

However, a total annual cost (investment plus operating cost) for a DRSS compares favorably with use of the MSFN, and the DRSS meets program requirements for real-time data and large amounts of video data.

The impact of these two alternatives is summarized in Table 5-8. To make a meaningful comparison of data rates and RF hardware components, the only parameters considered were: data rates, spacecraft antenna gain requirements, and spacecraft transmitter power requirements.

The following assumptions were made: (1) direct communication to MSFN = 2.228 GHz, (2) communication via DRSS = 14.5 GHz, (3) S/N = 10 db, and (4) MSFN use includes onboard recorders with high-speed data-dump capability.

The RF frequency for all down-link calculations is assumed fixed at 14 GHz, which was specified by the Space Station Phase B Program Definition study.*

The other system parameters are assumed to be a noise factor NF of ground receiver = 2.5 db, and a minimum acceptable S/N = 10 db.

Reliable present-day travelling-wave-tube transmitters are limited to about a 30-w output. It is assumed, however, that future spaceborne transmitters will be capable of considerably greater power output. Reliable transmitter power of up to about 1 kw is therefore assumed.

5.5.3 Real-Time Data Requirements

Directly related to the problem of data storage is the classification of data into realtime and nonreal time. All the DMS functions have at least one of the following realtime-data use requirements:

A. Onboard display and control.

B. Ground-based principal investigator interface.

C. Realtime reduction and evaluation of data.

*Space Station - Preliminary System Design Study, MDC-G0634, MDAC, July 1970.

Table 5-8

IMPACT OF DIFFERENT DOWN LINK PATHS ON SPACE STATION COMMUNICATION SYSTEM

DMS Impact on the Down-Link Communications System	MSFN	DRSS
1. Continuous Real-time Coverage	Limited realtime: 1440 minutes of data dumped while over ground station, plus bulk storage requirements as described in the text	Continuous coverage - no gaps
2. Initial Non-recurring Costs	Low	High
3. Space Attenuation (Space Station to ground)	132 db (at S-band)	207 db (at 14.5 GHz)
4. Impact of Space Attenuation on Space Station	Low-gain directional antenna required	High-gain directional antenna required, precision acquisition and tracking capability required
5. Impact on Space Station Transmitter Power Requirements	Present transmitters adequate	High-power transmitters required

The first two of the above requirements are a direct result of experiment procedures defined for the research clusters. The third is implied but becomes a system procedure as throughput requirements increase. Each relates to experiment management and control, and are directly related to man and to the requirements for his skills and training to successfully complete the experiment.

Realtime data flow from the sensors to the ground is required to enable control and evaluation interaction between the experiment and the principal investigator. Onboard systems (plus crew participation) can be used effectively to choose valid data and to eliminate faulty, irrelevant, or redundant data.

All such data that are removed either reduce the RF transmission problem or the weight of film to be returned via logistics spacecraft.

In particular, the experiment control center will be used for realtime experiment monitoring and control. Samples of video from onboard TV cameras will be transmitted in near real time to allow interactive involvement by the principal investigator. The data links will be accompanied by two-way voice communication For certain crucial experiments requiring a high degree of skill and training, control may be shifted to the ground if necessary, allowing discrete and digital commands to be issued from there.

On a longer-range basis, mission planning will also be performed at this facility. Planning includes the impact on logistics spacecraft to carry the experiments and consumables to the space platform; to return the film, recorded data, and physical samples to the experiment control center on the ground; and to provide crew rotation.

5.5.3.1 Image Processing

Based on the total equivalent bits per day, image and scanner data requirements comprise a large part of the total data requirements. The technical objectives of an image-processing subsystem are twofold:

A. Image enhancement by removal of distortion and random noise and compensation for sensor degradation.

B. Conversion to the data format and media desired by the user.

Image processing can be implemented by optical, analog, or digital techniques, each of which has unique advantages. These approaches have been considered and documented in the Space Station Phase B study.* Sophisticated onboard image processing has the following basic drawbacks:

A. It consumes an excessive amount of computer storage.

B. It requires bulky equipment, resulting in excessive weight, volume, and power requirements if implemented onboard.

C. It has an enormous spacecraft impact.

*Information Management System Study, IBM No. 70-K34-0001, April 1970, (p/o MDAC Space Station Program Study, Contract NAS8-25140)

The referenced information management study concluded that image processing should be accomplished on the ground rather than in the Space Station.

5.5.3.2 Data Compression Considerations

The principal investigators and the experiment designers have a responsibility to not generate data that are not strongly justified so that the rates and volume can be kept within manageable proportions. There are practical limits, considering the onboard weight, power, crew time, cost, and accumulation of data on the ground. The experimenter or user is, therefore, well advised to optimize his data collection requirements to minimize costs and to increase responsiveness to said requirements. The obvious option for a high-data-rate experiment is to limit its "ON" time (or running time) to periods when maximum probability of success occurs.

Whether data compression (redundancy removal being a more descriptive term) is possible in the DMS or experiment electronics depends on the nature of the data; in particular, whether the measurement contains new and useful information each time it is sampled, and whether all or only part of the data are meaningful. There are several methods for removing redundancy from raw data, and these methods will depend on the nature of the particular measurement. Typical data compression schemes are:

A. Output data only when the information changes; e.g., report only if a discrete signal changed from its previous state at the last sampling. This will require a storage element for each discrete signal. The data may be scanned to determine the data to be collected and transmitted. Each datum must carry an identification tag since the data output sequence will vary.

B. Output data only when outside preselected limits. After the data are sampled by the acquisition system, they are compared with values (high and low) stored for each measurement. If the data are within the prescribed limits, they are not formatted for transmission. Occasionally this program may be overridden to permit infrequent transmission of the actual measurement values.

C. Process raw data into usable information. This could take the form of summing the counts from radiation or particle counters so that the data would be in the form of a total count per unit time or time for predetermined count rather than transmitting each count or event as it occurs. Another form of simple processing would be control of the sampling rate to decrease the output. The sampling rate varies in relation to the rate at which the measurement is changing.

D. Output only usable information by eliminating the unwanted or unusable portions of the data. An example of this would be the editing and subsequent transmission of only that portion of an image that contains the objects of interest.

The measurement tasks identified in the research cluster descriptions must be considered individually for applicable data reduction techniques such that precision and content, as specified by the principal user(s) is not lost.

Image data are a major candidate for data reduction. Remote sensing research areas, such as Astronomy, Earth Observations, and some of the Space Physics disciplines, depend on recorded images for analysis as does analytical work involving microscopy; i.e., biology experiments that may be performed onboard the space vehicle. A number of these research areas will use high-resolution vidicons as detectors, resulting in large quantities of electrical data being generated.

The penalties of compressing electronic data by the methods described includes, in addition to the system costs, a loss of data reproducibility or accuracy, increased display required for editing, increased crewtime required for data selection, and increased onboard processor loading for execution of storage and compare operations associated with redundancy removal and limit checking.

Savings that are realized both in the onboard systems and on the ground result from storage and transmission capacity saved, data management cost reduction assignable to the data eliminated, and a reduction in ground handling costs of many functions within NASA's data facilities and again at the principal investigator's facility.

5.5.3.3 Data System Sizing

Estimates of the total data output of typical research cluster groupings is shown in Table 5-9. Three cases were postulated that exemplify an early (limited) capability, an intermediate capability, and a sophisticated capability corresponding to full response to requirements supporting the research clusters.

Table 5-9

SPACE STATION EXPERIMENT DATA REQUIREMENTS
SUMMARY FOR THREE TYPICAL GROUPINGS

BALANCED GROUPING - 10^{12} BITS/DAY	
Astronomy	1.4×10^{12}
Biomedicine	1.7×10^{10}
Man-Machine Evaluation	0.9×10^{10}
Earth Observations	9.9×10^{10}
Space Physics	2.4×10^{10}
Space Biology	1.3×10^{10}
Space Manufacturing	0.8×10^{10}
MEDIUM GROUPING - 10^{11} BITS/DAY	
Astronomy	2.0×10^{10}
Biomedicine	0.9×10^{10}
Man-Machine Evaluation	0.5×10^{10}
Earth Observations	5.0×10^{10}
Space Physics	1.2×10^{10}
Space Biology	0.6×10^{10}
Space Manufacturing	0.4×10^{10}
CORE GROUPING - 10^{10} BITS/DAY	
Astronomy	0.8×10^{10}
Biomedicine	1.6×10^{8}
Man-Machine Evaluation	0.3×10^{8}
Earth Observations	1.4×10^{10}

The core grouping is concerned with limited data in four scientific areas and does not include video processing. The medium grouping is shown for a larger integration of data handling requirements, including an allowance for video outputs. The balanced grouping is a representative estimate for the same model as the medium grouping, but with full allowance for typical instrumentation for complete data handling. Thus, the equivalent data being generated are spread

spread over two orders of magnitude in the range from 10^{10} to 10^{12} bits per day.

5.6 CONCEPTUAL SPACE FACILITY CONFIGURATION DEVELOPMENT

As instrumentation summaries were being prepared from the data contained in the Research Clusters in Appendix C, it became possible to compose layouts representing distinctive spacecraft facilities or laboratories for the proposed research. This effort was undertaken, and instrument matrices for the six scientific and technology categories were developed. These matrices (Appendix G) are an important tool for this concept presentation, and they also perform a useful function in the analysis of mission requirements, as explained in the planning example which is presented in Subsection 5.7.

The assignment of groups of instruments having common usage among research clusters, as indicated in the above-mentioned matrices, permits an assessment of spacecraft floorspace and volume. The groupings are a first step in deciding on possible assignments of instrument locations. These locations are then translated into interior and exterior interface requirements.

It is desirable to draft simplified facility layouts in order to estimate operational procedures and develop work flow estimates. One illustrative layout for a Communications and Navigation space laboratory is shown in Figure 5-47. The functional activities envision two main operational consoles for carrying out the proposed research. The experiment test bench would contain the proper instruments and controls necessary for signal patching and display. In addition, there would be controls available for pointing the antennas and for the launching and control of sub-satellites. The second main console would contain a data terminal and computer interface keyboard, signal display monitors, and status boards. Support equipment and activities, such as calibration and repair, are also shown. The integral facility can easily accommodate six experimentors. Any final laboratory layout would depend upon the development of detailed specifications for the hardware identified in the research clusters.

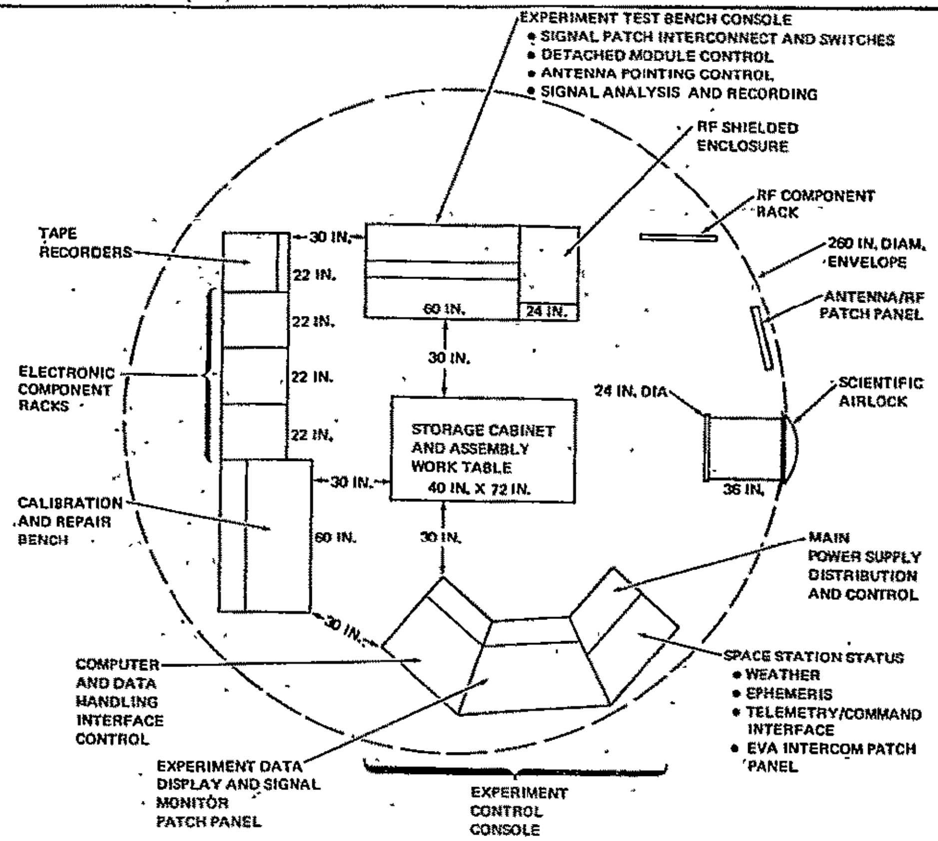


Figure 5-47. Conceptual Layout for Communications and Navigation Laboratory Work Center

Conceptual floor plans, such as the one shown, are generally scaled in accordance with accepted sizing standards and industrial practices. In this regard, the final facility layouts must incorporate considerations of human factors analysis, crew management, and safety. In many cases, the instrumentation volume was not given, and estimates were developed from conventional equipment descriptions found in commercial catalogs and brochures. The preliminary facility layouts will provide useful guidelines in terms of total volume and floor area requirements. More detailed engineering design is required, however, prior to the facilities being actually incorporated into a space vehicle.

The instrument matrices for the research categories and conceptual instrument and facility drawings are contained in Appendix G to this report. The drawings include several sketches of important environmental considerations affecting hardware design. The configurations provided are discussed in the following sub-paragraphs.

5.6.1 Biomedical Research Facility

The biomedical research facility consists of the basic instruments that are common to most measurements in the biomedical experiment group descriptions. Specific pieces of experimental apparatus that are not common to very many experiments in the cluster are arranged so that various items of equipment could be easily reconfigured for specific experiments.

5.6.2 Space Biotechnology Facility and Space Plant Biology Facility

Together these two facilities provide the major portion of the instrumentation requirements for the Space Biology research clusters.

5.6.3 Space Astronomy Instruments

Figures portraying examples of the major instruments (telescopes, collectors, antennas) and secondary instruments (analyzers, detectors, recorders), which dominate the configuration of an experimental space astronomy facility were derived from material contained in the OASF Study, Volume III, DAC 58143. These figures are included in Appendix G for reference.

5.6.4 Space Physics Laboratory

The Space Physics Laboratory consists of basic instruments that are common to most of the measurements in the physics and chemistry research clusters. Specific experiments that are not common to many experiments in the clusters are arranged so that various instruments could be easily reconfigured for specific experiments.

5.6.5 Plasma Physics Experiment Layout

Possible experimental configurations for cosmic-ray research are a topic to be analyzed in further depth to develop the tradeoff data offered by various configurations. A premature layout of such a facility may prove misleading, but it could be developed after analyzing tradeoffs, and it will include the types of basic instruments required. Included is a layout of the Barium Cloud experiment using a remote maneuvering subsatellite.

5.6.6 Communications/Navigation Research Facility and Communications/Navigation Antenna Facility

The two layouts portray major instruments within the work center functional areas (such as analyzer, comparator, and calibrators) and an antenna farm (such as dipole, helical, and horn), which will dominate the configuration of a manned experimental space Communications and Navigation facility.

5.6.7 Earth Observation Sensor Mountings

These layouts are typical of the sensor arrangements from the point of view of grouping the instruments that will most likely be required to function together. Although a number of the instruments are to be developed, the entire set of 22 sensors in a typical installation configuration has been established.

5.7 MISSION PLANNING EXAMPLE

Once the planning factors and guidelines that summarize the major characteristics of the various research requirements have been developed, it still remains to put together all of the important research program elements in a usable form for mission planning. It cannot be stressed too strongly that the need for reliable experiment information is essential at this point. Poorly selected data will not produce meaningful results. Therefore, a continuing program of refinement and updating of the research cluster descriptions must be instituted so that preliminary assumptions will be replaced with facts.

As previously stated, the basis for the methods developed in this study relies heavily on the critical issues as representing a body of research information valuable to the user community. This information, for analytical purposes, is assumed to have equivalent relevance for the intention of demonstrating methodology. Under this assumption, equal weighting is assigned to each critical issue, and a research cluster is given a level of importance in direct relationship to the number of critical issues represented by the research cluster description. Of course, once a priority system or an expression of preferential rating is derived, these relationships may be adjusted by weighting factors.

In the context of this study's data bank, a step-by-step procedure was developed to operate within the framework of the experiment measurements. The steps followed propose to:

A. Select a mission profile to serve as a mission model.

B. Filter the research cluster data for mission compatibility.

C. From Steps A and B above, select a set of mission candidates that meet the criteria and establish the objectives in terms of the composite set of critical issues.

D. Develop strategies for crew manning, experiment instrument weight, volume, and power, and their demand relationships.

E. Estimate the sensitivity of research to each of the strategies selected by analyzing the change in critical issues.

F. Iterate the steps taken to adjust the mission payload until the limiting mission constraints are met.

The steps shown are intended to assist the mission planner in exercising his intuition and judgement, when he is faced with the decisions inherent in the planning process. It provides a means of reviewing the consequences of a decision well in advance of an actual design committment. The fundamental planning parameters of spacecraft weight, volume, power, and crew size all blend together to form the basis for a design approach. Therefore, each of these parameters has been treated in the techniques employed in explaining the example. The basic assumptions stated at the outset of the problem are considered reasonable in gaining insight into the selection of experiments for the mission. It remains for the planner to improve upon the technique with practice, and by the substitution of real data for assumed information. Each place in the problem where an assumption was relevant will be so treated that the point of inference is clear.

5.7.1 Selecting a Mission Profile

To proceed into the problem, it was necessary to select certain mission criteria for illustrative purposes. The kinds of questions to be asked by the planner will deal with gross characteristics of the mission. Typical questions are, "Will it require low, medium, or synchronous orbit?" or "Is high-precision stabilization and pointing control required?" A set of such questions resulted in the formation of a mission plan employing the matrix of experimentation information described previously in Subsection 5.2.2, but expanded in format to include columns for easier screening, coding, and presentation.

The mission parameters selected for the example are:

A.	Orbit	Low altitude (<300 nmi) Medium inclination ($30^{\circ}<i<60^{\circ}$) No special considerations
B.	Spacecraft Pointing	Earth pointing Medium pointing accuracy (>10 sec)
C.	Spacecraft Demands	Nominal, not to exceed: a. Volume<100 cu ft b. 3500-w average power c. Weight<1000 lbm/research cluster
D.	Environment	No separate satellites Not acceleration-sensitive Cryogenics allowed No artificial-g No special atmosphere controls No high-temperature controls
E.	Crew	EVA allowed Crew as a subject permitted
F.	Special	Unlimited structure Real-time data handling required Photo development onboard No constraints on effluents No constraints on thermal cooling No constraints on EMI

The elimination process of screening and coding that was used is designed to be simple and straightforward. The other considerations that will be applied to influence the candidates chosen remain to be determined. If the number of entries becomes too unmanageable for manipulation by manual methods, data for the selection process using automatic data processing machines could be employed. Screening was conducted by marking the particular parameters that were selected into the mission planning worksheet. This is shown in Table 5-10 for all of the research clusters. Each entry in the matrix was checked to determine whether the cluster was qualified or disqualified in terms of the selected criteria. On the basis of the requirements, a determination is made to decide whether the constraints imposed are exceeded. The right-hand columns of the worksheet are appropriately marked with a code, and an entry is made in the proper column to indicate the research clusters to be eliminated.

Table 5-10 (page 1 of 7)

SCREENING MATRIX - MISSION CANDIDATE SELECTION

Research Cluster \ Mission Planning Parameter	Orbit – Altitude: Low (H < 300 nmi)	Orbit – Altitude: Med (300 < H < 1,000 nmi)	Orbit – Altitude: High (H > 1,000 nmi)	Orbit – Inclination: Low (i < 30°)	Orbit – Inclination: Med (30° < i < 60°)	Orbit – Inclination: High (i > 60°)	Special Orbit Requirements	Spacecraft Pointing – Orientn: Toward Earth	Spacecraft Pointing – Orientn: Toward Space	Spacecraft Pointing – Accuracy: High (< 10 sec)	Spacecraft Pointing – Accuracy: Med (10 sec - 30 mins)	Spacecraft Pointing – Accuracy: Low (> 30 mins)	Spacecraft Demand – Volume: High (> 100 ft^3)	Spacecraft Demand – Power (Avg): High (> 3,500 W)	Spacecraft Demand – Weight: High (> 1,000 lbm)	Environment Requirements: Separation (Free Flying) Required	Acceleration Sensitive	Cryogenics Required	Acceleration (Artificial Gravity) Required	Atmosphere Control	High Temperature	Crew Rqmt: EVA Required	Crew as Subject	Special Requirements: Structure	Shielding	Human Centrifuge	Animals	Real Time Data	Photo Development	Effluent Sensitive	EMI Sensitive	Thermal Control	Cooling Required	Elimination Criteria: Orbit Requirements	Pointing Requirements	Space Station Demand Requirements	Environment and Crew Requirements	Special Requirements	Mission Candidates
1-BM-4																							•										•						●
1-BM-5																											•	•					•						●
1-BM-6																							•										•						●
1-BM-7																							•					•	•										●
1-BM-8																							•										•						●
1-BM-10																							•										•						●
1-BM-12																											•	•				•	•						●
1-BM-13																							•										•						●
1-BM-14																							•										•						●
1-BM-15																	•						•			•							•				o	o	
1-BR-1																							•										•						●
1-BR-2																							•					•					•						●
1-BR-3																						•	•			•						•	•					o	
1-BR-4																	•						•			•							•				o	o	
1-MM-1																							•										•						●
1-MM-2											•						•						•					•					•				o		
1-MM-3																							•										•						●
1-MM-4																							•										•						●
1-MM-5																																							
1-LS-1											•						•		•										•				•				o		
Key		O	O			O			O	O			O	O	O	O	O		O							O													

Key
- O - Screened parameter
- • = Significant characteristic
- o = Elimination cause
- ● - Passed screening

Table 5-10 (page 2 of 7)

Research Cluster / Mission Planning Parameter	Orbit							Spacecraft Pointing					Spacecraft Demand			Environment Requirements						Crew Rqmt		Special Requirements										Elimination Criteria					
	Altitude			Inclination				Orientn		Accuracy			Volume	Power (Avg)	Weight																								
	Low (H < 300 nmi)	Med (300 < H < 1,000 nmi)	High (H > 1,000 nmi)	Low (i < 30°)	Med (30° < i < 60°)	High (i > 60°)	Special Orbit Requirements	Toward Earth	Toward Space	High (< 10 sec)	Med (10 sec - 30 mins)	Low (> 30 mins)	High (> 100 ft³)	High (> 3,500 W)	High (> 1,000 lbm)	Separation (Free Flying) Required	Acceleration Sensitive	Cryogenics Required	Acceleration (Artificial Gravity) Required	Atmosphere Control	High Temperature	EVA Required	Crew as Subject	Structure	Shielding	Human Centrifuge	Animals	Real Time Data	Photo Development	Effluent Sensitive	EMI Sensitive	Thermal Control	Cooling Required	Orbit Requirements	Pointing Requirements	Space Station Demand Requirements	Environment and Crew Requirements	Special Requirements	Mission Candidates
1-LS-2																	•	•	•										•				•				o		
1-LS-3																		•															•						●
1-LS-4																									•								•						●
1-LS-5																		•															•						●
1-LS-6																																	•						●
1-LS-7																																							●
1-LS-9																									•								•						●
1-LS-10																																	•						●
1-LS-11																																							●
1-LS-12																																							
1-EE-1																																	•						●
1-EE-2	•										•																												●
1-EE-3											•																						•						●
1-EE-4								•			•							•															•						●
1-EE-5								•																									•						●
1-OE-1											•											•						•					•						●
1-OE-2											•																						•						●
1-OE-3											•																	•											●
1-OE-4											•																												●
1-OE-5											•																												●

Key

- O Screened parameter
- • Significant characteristic
- o Elimination cause
- ● Passed screening

Table 5-10 (page 3 of 7)

Mission Planning Parameter / Research Cluster	Orbit: Altitude			Orbit: Inclination			Orbit	Spacecraft Pointing: Orientn		Spacecraft Pointing: Accuracy			Spacecraft Demand: Volume	Spacecraft Demand: Power (Avg)	Spacecraft Demand: Weight	Environment Requirements						Crew Rqmt		Special Requirements										Elimination Criteria					
	Low (H < 300 nmi)	Med (300 < H < 1,000 nmi)	High (H > 1,000 nmi)	Low (i < 30°)	Med (30° < i < 60°)	High (i > 60°)	Special Orbit Requirements	Toward Earth	Toward Space	High (< 10 sec)	Med (10 sec - 30 mins)	Low (> 30 mins)	High (> 100 Ω^3)	High (> 3,500 W)	High (> 1,000 lbm)	Separation (Free Flying) Required	Acceleration Sensitive	Cryogenics Required	Acceleration (Artificial Gravity) Required	Atmosphere Control	High Temperature	EVA Required	Crew as Subject	Structure	Shielding	Human Centrifuge	Animals	Real Time Data	Photo Development	Effluent Sensitive	EMI Sensitive	Thermal Control	Cooling Required	Orbit Requirements	Pointing Requirements	Space Station Demand Requirements	Environment and Crew Requirements	Special Requirements	Mission Candidates
2-VB-1																	•			•							•	•									o		
2-VB-2																	•	•									•	•									o		
2-VB-3																	•	•									•	•									o		
2-IN-1																	•															•							●
2-IN-2																	•															•							●
2-IN-3																	•																						●
2-P/T-1																			•																		o		
2-P/T-2																	•																						●
2-P/T-3																																					o		
2-PL-1																	•	•		•								•				•					o		
2-PL-2																	•	•		•								•				•					o		
2-PL-3																	•	•		•								•				•					o		
3-OW			•						•	•						•	•	•				•						•		•		•		o	o		o		
3-XR	•	•							•	•						•						•						•		•		•	•		o		o		
3-LF			•						•	•						•						•						•					•	o	o		o		
3-OB			•						•	•						•		•				•						•						o	o		o		
3-OS	•	•							•	•						•	•	•				•						•		•		•			o		o		

Note:
(1) These experiment clusters passed the "acceleration sensitive" filter because the requirement for $<10^{-4}$ g is not continuous (95%)

Key

O = Screened parameter
• = Significant characteristic
o = Elimination cause
● = Passed screening

Table 5-10 (page 4 of 7)

Research Cluster \ Mission Planning Parameter	Orbit – Altitude: Low (H < 300 nmi)	Orbit – Altitude: Med (300 < H < 1,000 nmi)	Orbit – Altitude: High (H > 1,000 nmi)	Orbit – Inclination: Low (i < 30°)	Orbit – Inclination: Med (30° < i < 60°)	Orbit – Inclination: High (i > 60°)	Orbit – Special Orbit Requirements	Spacecraft Pointing – Orientn: Toward Earth	Spacecraft Pointing – Orientn: Toward Space	Spacecraft Pointing – Accuracy: High (< 10 sec)	Spacecraft Pointing – Accuracy: Med (10 sec - 30 mins)	Spacecraft Pointing – Accuracy: Low (> 30 mins)	Spacecraft Demand – Volume: High (> 100 ft³)	Spacecraft Demand – Power (Avg): High (> 3,500 W)	Spacecraft Demand – Weight: High (> 1,000 lbm)	Environment Requirements – Separation (Free Flying) Required	Environment Requirements – Acceleration Sensitive	Environment Requirements – Cryogenics Required	Environment Requirements – Acceleration (Artificial Gravity) Required	Environment Requirements – Atmosphere Control	Environment Requirements – High Temperature	Crew Rqmt – EVA Required	Crew Rqmt – Crew as Subject	Special Requirements – Structure	Special Requirements – Shielding	Special Requirements – Human Centrifuge	Special Requirements – Animals	Special Requirements – Real-Time Data	Special Requirements – Photo Development	Special Requirements – Effluent Sensitive	Special Requirements – EMI Sensitive	Special Requirements – Thermal Control	Special Requirements – Cooling Required	Elimination Criteria – Orbit Requirements	Elimination Criteria – Pointing Requirements	Elimination Criteria – Space Station Demand Requirements	Elimination Criteria – Environment and Crew Requirements	Elimination Criteria – Special Requirements	Mission Candidates
4-P/C-1											•																												●
4-P/C-2											•								•														•				o		
4-P/C-3											•								•	•													•				o		
4-P/C-4											•			•			•																•			o	o		
4-P/C-5											•								•																		o		
4-P/C-6											•			•				•	•														•			o	o		
4-P/C-7											•																	•					•						●
4-P/C-8											•			•																			•			o			
4-P/C-9											•									•																			●
4-P/C-10											•								•	•													•				o		
4-P/C-11											•								•									•									o		
4-PP-1											•					•																					o		
4-PP-2			•	•							•					•																		o			o		
4-PP-3											•					•												•									o		
4-CR-1 - 10									•		•			•	•			•		•				•	•										o	o			
5-N-1	•	•				•		•				•						•																o					
5-N-2	•	•			o	•		•			•							•																					●
Key		○	○			○			○	○			○	○	○	○	○		○							○													

○ Screened parameter
• Significant characteristic
o Elimination cause
● Passed screening

Table 5-10 (page 5 of 7)

Research Cluster \ Missing Planning Parameter	Orbit: Altitude: Low (H < 300 nmi)	Orbit: Altitude: Med (300 < H < 1,000 nmi)	Orbit: Altitude: High (H > 1,000 nmi)	Orbit: Inclination: Low (i < 30°)	Orbit: Inclination: Med (30° < i < 60°)	Orbit: Inclination: High (i > 60°)	Special Orbit Requirements	Spacecraft Pointing: Orientn: Toward Earth	Spacecraft Pointing: Orientn: Toward Space	Spacecraft Pointing: Accuracy: High (< 10 sec)	Spacecraft Pointing: Accuracy: Med (10 sec - 30 mins)	Spacecraft Pointing: Accuracy: Low (> 30 mins)	Spacecraft Demand: Volume: High (> 100 ft^3)	Spacecraft Demand: Power (Avg): High (> 3,500 W)	Spacecraft Demand: Weight: High (> 1,000 lbm)	Environment Requirements: Separation (Free Flying) Required	Environment Requirements: Acceleration Sensitive	Environment Requirements: Cryogenics Required	Environment Requirements: Acceleration (Artificial Gravity) Required	Environment Requirements: Atmosphere Control	Environment Requirements: High Temperature	Crew Rqmt: EVA Required	Crew Rqmt: Crew as Subject	Special Requirements: Structure	Special Requirements: Shielding	Special Requirements: Human Centrifuge	Special Requirements: Animals	Special Requirements: Real Time Data	Special Requirements: Photo Development	Special Requirements: Effluent Sensitive	Special Requirements: EMI Sensitive	Special Requirements: Thermal Control	Special Requirements: Cooling Required	Elimination Criteria: Orbit Requirements	Elimination Criteria: Pointing Requirements	Elimination Criteria: Space Station Demand Requirements	Elimination Criteria: Environment and Crew Requirements	Elimination Criteria: Special Requirements	Mission Candidates
5-P-1	•				•	•		•			•																												●
5-P-2			•	•				•			•										•													o					
5-P-3	•				•	•		•			•																												●
5-P-4	•	•						•			•					•																					o		
5-TF-1																						•											•						●
5-TF-2																																	•						●
5-CS-1					•	•		•				•																					•						●
5-CS-2					•	•		•				•																•					•						●
5-NS-1					•	•		•			•																						•						●
5-NS-2					•	•		•			•																	•					•						●
5-NS-3					•	•		•			•																												●
5-NS-4					•	•		•			•																	•											
5-NS-5					•	•		•			•																												
5-NS-6					•	•		•			•																	•											
6-AF-1	•				•	•		•			•			•				•				•		•					•	•	•					o			
6-AF-2	•				•	•		•			•			•				•				•		•						•	•					o			
6-AF-3	•				•	•		•			•			•				•				•								•	•					o			
Key		O	O			O			O	O			O	O	O	O	O		O							O													

O = Screened parameter
• = Significant characteristic
o - Elimination cause
● - Passed screening

Table 5-10 (page 6 of 7)

Research Cluster \ Mission Planning Parameter	Orbit: Altitude: Low (H < 300 nmi)	Med (300 < H < 1,000 nmi)	High (H > 1,000 nmi)	Orbit: Inclination: Low (i < 30°)	Med (30° < i < 60°)	High (i > 60°)	Special Orbit Requirements	Spacecraft Pointing: Orientn: Toward Earth	Toward Space	Accuracy: High (< 10 sec)	Med (10 sec - 30 mins)	Low (> 30 mins)	Spacecraft Demand: Volume: High (> 100 ft^3)	Power (Avg): High (> 3,500 W)	Weight: High (> 1,000 lbm)	Environment Requirements: Separation (Free Flying) Required	Acceleration Sensitive	Cryogenics Required	Acceleration (Artificial Gravity) Required	Atmosphere Control	High Temperature	Crew Rqmt: EVA Required	Crew as Subject	Special Requirements: Structure	Shielding	Human Centrifuge	Animals	Real Time Data	Photo Development	Effluent Sensitive	EMI Sensitive	Thermal Control	Cooling Required	Elimination Criteria: Orbit Requirements	Pointing Requirements	Space Station Demand Requirements	Environment and Crew Requirements	Special Requirements	Mission Candidates
6-AF-4	●				●	●		●			●			●				●				●						●		●	●					o			
6-AF-5	●				●	●		●			●							●				●		●				●	●	●	●								●
6-EP-1	●				●	●		●			●			●								●								●						o			
6-EP-2	●				●	●		●			●			●								●								●						o			
6-G/C-1	●				●	●		●			●			●								●							●	●									●
6-G-1	●					●		●			●			●				●				●								●	●			o		o			
6-G-2	●				●	●		●			●			●				●				●		●					●	●	●					o			
6-G-3	●				●	●		●			●			●				●				●						●	●	●	●								●
6-G-4	●				●	●		o			●			●				●				●							●	●	●					o			
6-G-5	●				●	●		●			●			●				●				●							●	●	●					o			
6-G-6	●					●		●			●			●				●				●								●				o		o			
6-H-1	●				●	●		●			●							●				●							●	●	●								●
6-H-2	●				●	●		●			●											●						●	●	●	●								●
6-H-3	●				●	●		●			●			●				●				●							●	●	●					o			
6-H-4	●					●		●			●							●				●							●	●	●			o					
6-H-5	●				●	●		●			●							●				●							●	●	●								●
6-H-6	●				●	●		●			●							●				●							●	●	●								●
6-H-7	●				●	●		●			●			●				●				●							●	●	●					o			
Key		O	O		O				O	O			O	O	O	O	O		O							O													

O = Screened parameter

● = Significant characteristic

o = Elimination cause

● = Passed screening

Table 5-10 (page 7 of 7)

Research Cluster \ Mission Planning Parameter	Orbit – Altitude – Low (H < 300 nmi)	Orbit – Altitude – Med (300 < H < 1,000 nmi)	Orbit – Altitude – High (H > 1,000 nmi)	Orbit – Inclination – Low (i < 30°)	Orbit – Inclination – Med (30° < i < 60°)	Orbit – Inclination – High (i > 60°)	Orbit – Special Orbit Requirements	Spacecraft Pointing – Orientn – Toward Earth	Spacecraft Pointing – Orientn – Toward Space	Spacecraft Pointing – Accuracy – High (<10 sec)	Spacecraft Pointing – Accuracy – Med (10 sec - 30 mins)	Spacecraft Pointing – Accuracy – Low (>30 mins)	Spacecraft Demand – Volume – High (>100 ft^3)	Spacecraft Demand – Power (Avg) – High (>3,500 W)	Spacecraft Demand – Weight – High (>1,000 lbm)	Environment Requirements – Separation (Free Flying) Required	Environment Requirements – Acceleration Sensitive	Environment Requirements – Cryogenics Required	Environment Requirements – Acceleration (Artificial Gravity) Required	Environment Requirements – Atmosphere Control	Environment Requirements – High Temperature	Crew Rqmt – EVA Required	Crew Rqmt – Crew as Subject	Special Requirements – Structure	Special Requirements – Shielding	Special Requirements – Human Centrifuge	Special Requirements – Animals	Special Requirements – Real Time Data	Special Requirements – Photo Development	Special Requirements – Effluent Sensitive	Special Requirements – EMI Sensitive	Special Requirements – Thermal Control	Special Requirements – Cooling Required	Elimination Criteria – Orbit Requirements	Elimination Criteria – Pointing Requirements	Elimination Criteria – Space Station Demand Requirements	Elimination Criteria – Environment and Crew Requirements	Elimination Criteria – Special Requirements	Mission Candidates
6-M-1	•				•	•		•			•							•				•								•	•								●
6-M-2	•	•			•	•		•			•											•								•	•								●
6-M-3	•							•		•												•								•	•				o				
6-M-4																	•			•									•								o		
6-M-5	•				•	•		•			•											•						•		•									●
6-M-6	•			•				•			•							•				•							•	•	•								●
6-Ø-1	•				•			•			•							•				•							•	•	•								●
6-Ø-2	•				•			•			•							•				•							•	•	•								●
6-Ø-3	•				•			•			•							•				•							•	•	•								●
6-Ø-4	•				•			•			•											•							•	•	•								●
6-Ø-5	•				•			•			•											•							•	•	•								●
6-Ø-6	•				•			•			•							•				•							•	•	•								●
6-Ø-7	•				•			•			•											•							•	•	•								●
Key		O	O			O			O	O			O	O	O	O	O		O							O													

O = Screened parameter
• = Significant characteristic
o = Elimination cause
● = Passed screening

In the example, the clusters that were removed from further consideration are identified by an open circle in the proper elimination criteria column. Those that passed the basic criteria were given a solid circle and are accepted as being mission-compatible. It was convenient at this stage to also compile a summary of the weight, volume, and power for the three thresholds (low, medium, and high), as shown in Table 5-11. This table is to provide data used in summing the research instrumentation requirements.

5.7.2 Screening of Candidate Research Clusters

From the set of research clusters screened as being mission-compatible in the previous step, a set of flight candidates must be selected. The final set may or may not include all of the mission-compatible clusters. This decision will depend on whether or not a large enough space research facility is planned. The process of selection will undoubtedly involve the balancing of many conflicting requirements that extend beyond the scope of this methodology. But this approach can help to establish the guidelines and constraints that relate directly to the spacecraft configuration, and may even provide indications of what to expect by way of impact on operations and the logistic system. However, the problems of scheduling and budget, the final selection of the size of the crew, or even whether a manned space research facility will be used, pose questions that will in part have influencing effects found completely outside of this methodology.

Returning to the example, all of the mission-compatible clusters identified in the previous section would be reviewed and considered as a normal mission-planning exercise. In this example, however, the selection process is limited to the Earth Observations family of research clusters in order to maintain a reasonable size and still provide a comprehensive guide. A total of 18 research clusters in Earth Observations passed the screening process. It may be seen from the table that excessive power requirements became the primary factor in eliminating 12 other clusters in this research discipline. Research Cluster 6-M-4 was eliminated because it exceeded sensitive acceleration levels. Three other clusters required orbit inclinations above the limit set by the mission plan.

Table 5-11 (page 1 of 5)

DEMANDS OF WEIGHT, VOLUME, AND POWER

Research Discipline	Spacecraft Demand Categories: Weight		Volume		Power	
	≤1,000 lb	>1,000 lb	<100 ft^3	>100 ft^3	≤3,500 w	>3,500 w
Manned Spaceflight Capability						
Biomedical		1-BM-4 (1566)	1-BM-4 (83)		1-BM-4 (100)	
		1-BM-5 (3602)		1-BM-5 (341)	1-BM-5 (240)	
		1-BM-6 (1809)		1-BM-6 (148)	1-BM-6 (350)	
		1-BM-7 (1116)	1-BM-7 (63)		1-BM-7 (1)	
		1-BM-8 (1074)	1-BM-8 (66)		1-BM-8 (40)	
		1-BM-10 (1263)	1-BM-10 (61)		1-BM-10 (200)	
		1-BM-12 (3347)		1-BM-12 (279)	1-BM-12 (100)	
		1-BM-13 (1380)	1-BM-13 (82)		1-BM-13 (50)	
	1-BM-14 (457)		1-BM-14 (39)		1-BM-14 (20)	
		1-BM-15 (1551)		1-BM-15 (1765)	1-BM-15 (280)	
Man-Machine					1-MM-1 (50)	
		1-MM-2 (1283)	1-MM-2 (99)		1-MM-2 (40)	
		1-MM-3 (1153)	1-MM-3 (78)		1-MM-3 (40)	
		1-MM-4 (2172)		1-MM-4 (354)	1-MM-4 (100)	
	1-MM-5 (352)		1-MM-5 (25)		1-MM-5 (345)	
Behavioral Research		1-BR-1 (6035)		1-BR-1 (2869)	1-BR-1 (180)	
		1-BR-2 (1345)	1-BR-2 (70)		1-BR-2 (50)	
		1-BR-3 (1002)	1-BR-3 (48)		1-BR-3 (47)	
		1-BR-4 (2271)		1-BR-4 (1764)	1-BR-4 (200)	
Life Support and Protective Systems		1-LS-1 (1162)	1-LS-1 (59)		1-LS-1 (200)	
	1-LS-2 (251)		1-LS-2 (10)		1-LS-2 (800)	
	1-LS-3 (14)		1-LS-3 (1)		1-LS-3 (1000)	
		1-LS-4 (1161)	1-LS-4 (56)		1-LS-4 (100)	
		1-LS-5 (1034)	1-LS-5 (49)		1-LS-5 (630)	
		1-LS-6 (1207)	1-LS-6 (61)		1-LS-6 (700)	
	1-LS-7 (962)		1-LS-7 (50)		1-LS-7 (300)	
	1-LS-8 (-)		1-LS-8 (-)		1-LS-8 (-)	
	1-LS-9 (385)		1-LS-9 (56)		1-LS-9 (500)	
	1-LS-10 (250)		1-LS-10 (9)		1-LS-10 (1000)	
		1-LS-11 (1224)	1-LS-11 (60)		1-LS-11 (-)	

Table 5-11 (page 2 of 5)

DEMANDS OF WEIGHT, VOLUME, AND POWER

	Spacecraft Demand Categories					
	Weight		Volume		Power	
Research Discipline	≤1,000 lb	>1,000 lb	<100 ft³	>100 ft³	≤3,500 w	3,500 w
Manned Spaceflight Capability (Cont'd)						
Engineering Experiments		1-EE-1 (2800)	1-EE-1 (70)		1-EE-1 (1[illegible])	
	1-EE-2 (797)			1-EE-2 (6506)	1-EE-2 (550)	
		1-EE-3 (1168)	1-EE-3 (34)		1-EE-3 (530)	
	1-EE-4 (910)		1-EE-4 (33)		1-EE-4 (100)	
	1-EE-5 (662)		1-EE-5 (42)		1-EE-5 (50)	
Operations Experiments	1-OE-1 (941)		1-OE-1 (61)		1-OE-1 (400)	
		1-OE-2 (1701)		1-OE-2 (108)	1-OE-2 (200)	
		1-OE-3 (1125)	1-OE-3 (54)		1-OE-3 [illegible]	
Space Biology						
Vertebrates		2-VB-1 (3608)		2-VB-1 (5263)	2-VB-1 (450)	
		2-VB-2 (3608)		2-VB-2 (5263)	2-VB-2 (450)	
		2-VB-3 (3608)		2-VB-3 (5263)	2-VB-3 (450)	
Invertebrates		2-IN-1 (2688)		2-IN-1 (5160)	2-IN-1 (30)	
		2-IN-2 (243[illegible])		2-IN-2 (5143)	2-IN-2 (60)	
		2-IN-3 (3244)		2-IN-3 (5166)	2-IN-3 (60)	
Protists and Tissues		2-P/T-1 (1817)		2-P/T-1 (5160)	2-P/T-1 (410)	
		2-P/T-2 (1671)		2-P/T-2 (2060)	2-P/T-2 (450)	
		2-P/T-3 (3222)		2-P/T-3 (5172)	2-P/T-3 (590)	
Plant Life		2-PL-1 (3179)		2-PL-1 (4880)	2-PL-1 (265)	
		2-PL-2 (3179)		2-PL-2 (4960)	2-PL-2 (265)	
		2-PL-3 (3179)		2-PL-3 (4880)	2-PL-3 (265)	
Space Astronomy		3-OW (2350)		3-OW (1891)	3-OW (930)	
		3-XR (1787)		3-XR (682)	3-XR (406)	
		3-LF (2182)		3-LF (259)	3-LF (366)	
		3-OB (3482)		3-OB (2064)	3-OB (170)	
		3-OS (2952)		3-OS (471)	3-OS (170)	

Table 5-11 (page 3 of 5)

DEMANDS OF WEIGHT, VOLUME, AND POWER

Research Discipline	Weight ≤1,000 lb	Weight >1,000 lb	Volume <100 ft^3	Volume >100 ft^3	Power ≤3,500 w	Power >3,500 w
Space Physics/Chemistry	4-P/C-1 (352)	4-P/C-2 (1479)	4-P/C-1 (51)	4-P/C-9 (148)	4-P/C-1 (750)	4-P/C-4 (5000)
	4-P/C-4 (582)	4-P/C-3 (1802)	4-P/C-2 (55)	4-P/C-11 (114)	4-P/C-2 (400)	4-P/C-6 (5000)
	4-P/C-7 (292)	4-P/C-5 (1048)	4-P/C-3 (64)		4-P/C-3 (30)	4-P/C-8 (5000)
	4-P/C-10 (200)	4-P/C-6 (1569)	4-P/C-4 (28)		4-P/C-5 (200)	
	4-P/C-11 (766)	4-P/C-8 (1027)	4-P/C-5 (65)		4-P/C-7 (2000)	
		4-P/C-9 (1050)	4-P/C-6 (75)		4-P/C-9 (175)	
			4-P/C-7 (22)		4-P/C-10 (250)	
			4-P/C-8 (58)		4-P/C-11 (20)	
			4-P/C-10 (17)			
Space Plasma Physics					4-PP-1 (-)	
					4-PP-2 (60)	
					4-PP-3 (-)	
Space Cosmic Ray Physics						4-CR-1 (10000)
						4-CR-2 (10000)
						4-CR-3 (10000)
						4-CR 4 (10000)
						4-CR-5 (10000)
						4-CR-6 (10000)
						4-CR-7 (10000)
						4-CR-8 (10000)
						4-CR-9 (10000)
						4-CR-10 (10000)
Communications and Navigation						
Noise		5-N-1 (1688)		5-N-1 (180)	5-N-1 (25)	
		5-N-2 (1675)		5-N-2 (784)	5-N-2 (25)	
Propagation		5-P-1 (1646)		5-P-1 (122)	5-P-1 (25)	
		5-P-2 (1650)		5-P-2 (195)	5-P-2 (25)	
		5-P-3 (1415)		5-P-3 (129)	5-P-3 (25)	
					5-P-4 (50)	

Table 5-11 (page 4 of 5)
DEMANDS OF WEIGHT, VOLUME, AND POWER

Research Discipline	Spacecraft Demand Categories: Weight ≤1,000 lb	Weight >1,000 lb	Volume <100 ft³	Volume >100 ft³	Power ≤3,500 w	Power >3,500 w
Communications and Navigation (Cont'd)						
Test Facility	5-P-4 (950)			5-P-4 (761)	5-TF-1 (300)	
		5-TF-1 (2414)		5-TF-1 (315)	5-TF-2 (300)	
Communications Systems		5-TF-2 (3154)		5-TF-2 (1000)	5-CS-1 (350)	
		5-CS-1 (1646)		5-CS-1 (822)	5-CS-2 (500)	
Navigation Systems	5-CS-2 (580)		5-CS-2 (34)		5-NS-1 (50)	
	5-NS-1 (430)		5-NS-1 (23)		5-NS-2 (500)	
	5-NS-2 (558)		5-NS-2 (31)		5-NS-3 (50)	
	5-NS-3 (565)			5-NS-3 (807)	5-NS-4 (25)	
		5-NS-4 (1175)		5-NS-4 (782)	5-NS-5 (25)	
	5-NS-5 (940)			5-NS-5 (743)	5-NS-6 (50)	
		5-NS-6 (1107)	5-NS-6 (72)			
Earth Observations						
Agriculture, Forest and Range Resources		6-AF-5 (4385)		6-AF-5 (174)	6-AF-5 (2200)	6-AF-1 ([illegible]475)
						6-AF-2 (4600)
						6-AF-3 (4600)
						6-AF-4 (4600)
Earth Physics (Incl. Geodesy)					6-EP-1 (1300)	6-EP-2 (4000)
Geography, Cartography, and Cultural Resources		6-G/C-1 (3110)		6-G C-1 (117)		6-G/C-1 (4[illegible])
Geology		6-G-3 (4068)		6-G-3 (243)	6-G-3 (3300)	6-G-1 (3900)
						6-G-2 (3900)
						6-G-3 (7401)
						6-G-4 (4009)
						6-G-5 (3909)
						6-G-6 (3[illegible])
Hydrology and Water Resources		6-H-1 (3174)		6-H-1 (119)	6-H-4 (320[illegible])	6-H-1 (4719)
		6-H-2 (2368)		6-H-2 (173)	6-H-6 (3028	6-H-2 (5526)
		6-H-5 (2791)		6-H-5 (192)		6-H-3 (3800)
		6-H-6 (2011)	6-H-6 (71)			6-H-5 (5403)
						6-H-7 (3[illegible])

Table 5-11 (page 5 of 5)
DEMANDS OF WEIGHT, VOLUME, AND POWER

Research Discipline	Spacecraft Demand Categories: Weight		Volume		Power	
	≤1,000 lb	>1,000 lb	<100 ft^3	>100 ft^3	≤3,500 w	>3,500 w
Earth Observations (Cont'd)						
Meteorology	6-M-2 (832) 6-M-5 (970)	6-M-1 (1473)	6-M-1 (34) 6-M-2 (11) 6-M-5 (21)		6-M-1 (2066) 6-M-2 (1906) 6-M-3 (65) 6-M-4 (200) 6-M-5 (1968) 6-M-6 (2852)	
Oceanography and Marine Resources		6-O-1 (2254) 6-O-2 (3349) 6-O-3 (2184) 6-O-4 (1906) 6-O-5 (2241) 6-O-6 (3396) 6-O-7 (1896)	6-O-1 (83) 6-O-3 (81) 6-O-7 (82)	6-O-2 (145) 6-O-4 (148) 6-O-5 (170) 6-O-6 (142)	6-O-1 (3077) 6-O-3 (2909) 6-O-7 (2843)	6-O-2 (3729) 6-O-4 (5218) 6-O-5 (5213) 6-O-6 (4693)

Although taken at face value in this example, screening in an actual situation would call for careful reconsideration of each of the eliminated candidates to see whether any minor compromises would allow a reinstatement of the intended research. Suffice it to say that the 18 successful candidates are taken to be a representative sample for the purposes of the example. The next step calls for developing grouping strategies to combine the most advantageous features of the research cluster instrumentation and crew requirements.

Recalling that instrument matrices were developed for each discipline, it was appropriate to prepare a table in matrix format that would reflect the assignment of instruments and the estimated unit weight, power, and volume of each sensor system. This methodology has been prepared on the assumption that payload weight, volume, and power are extremely important, along with crew demand, when it comes to the selection of experiments that will actually be flown. The objective of this step is to develop the demands that the planner can expect in relation to weight, volume, and power. Crew requirements are important enough for them to be broken out and treated separately.

Important data on the 18 research clusters that are compatible with the example mission and that are part of the Earth Observations scientific discipline are listed in Table 5-12. In the first row of the table, the symbol for the research cluster is followed by the number of critical issues that that particular research cluster answers. Next is the number of instruments required. A series of ones and zeros are placed in the columns corresponding to the names of the instruments along the top of the table. This forms a truth table to indicate whether or not the research cluster requires a given instrument.

Finally, in the last three rows on the right are listed the total weight, volume, and power of all of the instruments required by the research cluster. Across the top of the chart, in the columns beside the instrument names, are listed the individual unit weights, volumes, and power requirements of each instrument. The blanks in these columns indicate that the value is either insignificant or unknown. In the bottom row of the table are the summed number of research clusters in which the particular instrument is used.

TABLE 5-12

WORKSHEET - EQUIPMENT MATRIX (EXAMPLE)

No.	Instrument Name	Weight (lb)	Volume (ft³)	Avg Power (w)
1	Calibration Devices and Sensors	--	--	--
2	Camera - Metric	300	21	780
3	Camera - Multispectral	275	8	1120
4	Camera - Photo Imaging	87	2	163
5	Computer - General Purpose	40	1	150
6	Control Console - Sensor Pointing	200	24	--
7	Console - Data Reduction	150	12	--
8	Cooling System - Cryogenic	250	4	--
9	CRT - Display/Monitor	60	1	100
10	Data-Collection System	11	--	8
11	Detector - Sferics, UHF	22	3	6
12	Facility - Film Development	150	6	--
13	Intervalometer	25	1	25
14	Radar - Imager	620	112	2500
15	Radiometer - Chopper	34	1	5
16	Radiometer - Microwave Scanner	200	10	25
17	Radiometer - Temperature Profile	24	1	15
18	Recorder - Mag. Tape - Voice/Video	750	7	1800
19	Scanner - Multispectral 10-Band	300	19	190
20	Scatterometer - Altimeter Radar	75	1	130
21	Sensor - Ocean Color	13	1	6
22	Sounder - Temperature IR	45	2	60
23	Spectrometer - Absorption	30	1	18
24	Spectrometer - Filter Wedge	30	1	7
25	Spectrometer - Interferometer	35	2	24
26	Spectrometer - IR Satellite	70	2	30
27	Telescope - Tracking Boresight	850	38	540
28	Telescope - Tracking Multispectral	850	38	540
29	Vidicon-Film Scanning	--	1	--
	Total	5496	320	8242

No.	Research Cluster	Number of Critical Issues	Total No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	Weight (LBM)	Volume (Ft³)	Avg Power (watts)
1	6-AF-5	4	19	1	1	1	1	1	0	1	1	1	1	1	1	1	0	0	1	0	1	1	0	0	0	0	1	1	0	1	1	0	4385	174	5478
2	6-G/C-1	1	11	1	1	1	0	0	0	1	1	1	0	0	1	1	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	3110	·117	4555
3	6-G-3	3	17	1	1	1	1	1	0	1	1	1	1	0	1	1	1	0	1	0	1	1	0	0	0	0	0	0	0	1	0	1	4068	243	7401
4	6-H-1	6	14	1	1	1	0	1	0	1	1	1	1	0	1	1	0	0	0	0	1	1	0	1	0	0	0	0	0	1	0	0	3174	119	4719
5	6-H-2	6	12	1	1	0	1	1	0	1	0	1	1	0	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	2368	173	5526
6	6-H-5	4	11	1	1	0	0	0	0	1	1	1	1	0	1	0	1	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	2791	192	5403
7	6-H-6	2	10	1	1	0	0	1	0	1	1	1	1	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	2011	71	3028
8	6-M-1	5	12	1	0	0	0	0	0	1	1	1	0	0	0	1	0	1	0	1	1	0	0	0	1	0	1	1	1	0	0	0	1473	34	2066
9	6-M-2	6	4	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	832	11	1906
10	6-M-5	6	4	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	970	21	1968
11	6-M-6	5	15	1	1	0	0	0	0	1	1	1	0	1	1	1	0	1	0	1	1	0	0	0	1	0	1	1	1	0	0	0	1945	64	2852
12	6-O-1	8	13	1	1	0	0	1	0	1	1	1	1	0	1	0	0	0	1	0	1	1	0	1	0	1	0	0	0	0	0	0	2254	83	3077
13	6-O-2	9	15	1	1	0	0	1	1	1	1	1	1	0	1	0	0	0	1	0	1	1	1	1	0	0	0	0	0	1	0	0	3349	145	3729
14	6-O-3	9	11	1	1	0	0	0	0	1	1	1	1	0	1	0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	2184	81	2909
15	6-O-4	10	7	0	1	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1	1906	148	5218
16	6-O-5	4	9	0	1	0	0	0	0	1	0	1	1	0	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	2241	170	5213
17	6-O-6	8	14	1	1	1	0	0	1	1	1	1	1	0	1	1	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	0	3396	142	4693
18	6-O-7	2	9	0	1	0	0	0	1	1	0	1	1	0	1	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	1896	82	2843
	Each Inst Σ			14	15	5	3	8	3	16	12	16	13	3	15	7	5	2	9	2	18	10	4	4	2	2	3	3	2	6	1	4			

Matrix key: 1 = Required
0 = None

Using Table 5-12, empirical curves were derived. These curves were developed by using several desirable instrumentation strategies in selecting the order in which a given cluster is added to the candidates for flight. In general, a planner will have some objective in mind as he considers the addition of research clusters to the set that he has already chosen. The objectives will take the form of such design considerations as keeping weight to a minimum, answering the most critical issues possible for the least amount of volume, and making the least demand on the power system.

Strategies that reflect these kinds of objectives were formulated and used to develop the curves presented later.

The following alternative strategies are those that were used in this mission example:

A. Addition of a minimum number of instruments required to gain the next highest increment in critical issues answered.

B. Adding in descending order the instruments in accordance with the number of research clusters with which they are used.

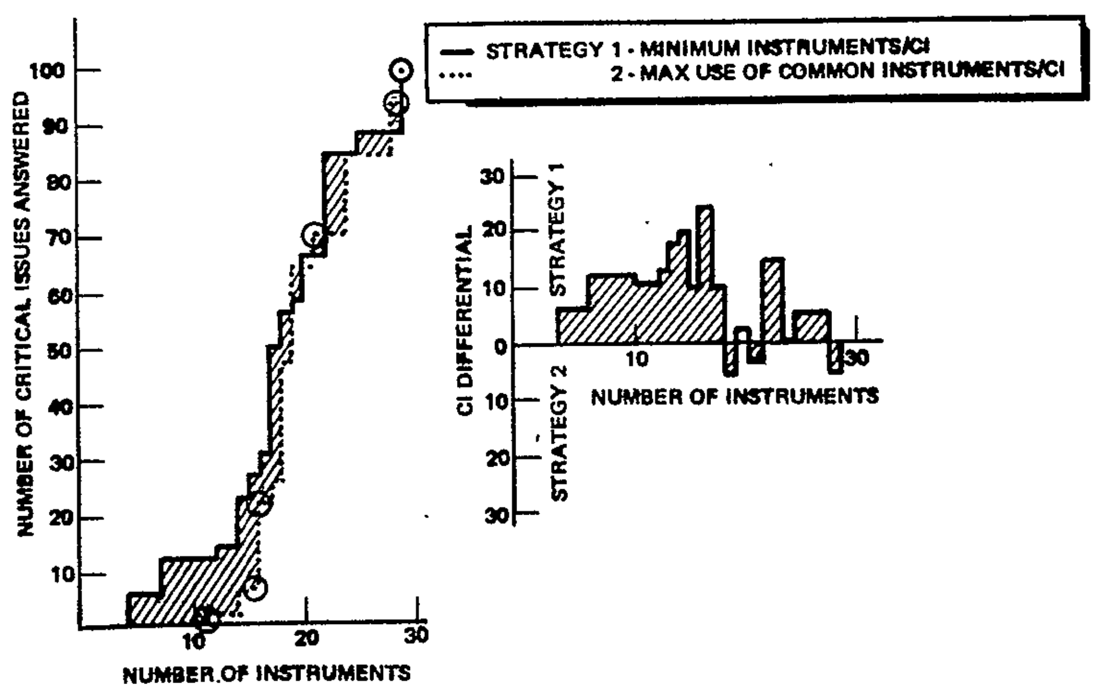
C. Adding research clusters in ascending order of their weight per critical issues answered.

D. Adding research clusters in ascending order of the total instrument weight required by the cluster.

E. Adding clusters in ascending order of total instrument volume required by the cluster.

F. Adding clusters in descending order of the number of critical issues answered.

Strategies A and B, above, were used to demonstrate the analysis technique. By referring to the data found in Table 5-12, the instrument population for each research cluster was then inspected. It is evident from the table that research clusters 6-M-2 and 6-M-5 require the smallest number of instruments (any four) for equal critical issues (6). These groupings were therefore assigned the first ordering sequence positions. Taken in ascending order, the results are plotted, shown in Figure 5-48. The worksheets used in the process are included as Tables 5-13 and 5-14. The second plot of Figure 5-48 is derived by subtracting the strategy values obtained for critical issues for each of the instruments taken in order. This area plot indicates a clearly favorable position for Strategy 1 over Strategy 2, through the nineteenth equivalent instrument and up to the fifty-eighth critical issue. At that point, the advantage disappears. This kind of information exposes the effects of each strategy under the condition of limited research, in deciding the proper course of action. It remains to expand the analysis to include not only a selective instrument population but also the effects of weight, volume, and power. This information is presented by graphs of the results in Figures 5-49 through 5-51.



5-48

Figure 5-48. Mission Analysis of Instrumentation-Earth Observations

Table 5-13

SENSITIVITY ANALYSIS WORKSHEET - STRATEGY 1

STRATEGY: ADD MINIMUM NUMBER OF INSTRUMENTS NECESSARY TO INCREASE NUMBER OF CRITICAL ISSUES ANSWERED

Step	Instr Added	Research Cluster Added	No. of C.I. RC	No. of C.I. Cum	Instr Wt (lbm)	Cum Wt	Instr Vol (ft^3)	Cum Vol	Instr Pwr (W)	Cum Pwr
1	1				-		-		-	
2	9				60	60	1	1	100	100
3	11				22	82	3	4	6	106
4	18	6-M-2	6	6	750	832	7	11	1800	1906
5	5				40	872	1	12	150	2056
6	7				150	1022	12	24	-	2056
7	23	6-M-5	6	12	30	1052	1	25	18	2074
8	2				300	1352	21	46	780	2854
9	8				250	1602	4	50	-	2854
10	10				11	1613	-	50	8	2862
11	12				150	1763	6	56	-	2862
12	19	6-H-6	2	14	300	2063	19	75	190	3052
13	16				200	2263	10	85	25	3077
14	21	6-Ø-1, 6-Ø-3	17	31	13	2276	1	86	6	3083
15	14	6-H-5	4	35	620	2893	112	198	2500	5583
16	29	6-Ø-5	4	39	-	2896	1	199	-	5583
17	20	6-Ø-4	10	49	75	2971	1	200	130	5713
18	4	6-H-2	6	55	87	3058	2	202	163	5876
19	6	6-Ø-7	2	57	200	3258	24	226	-	5876
20	27	6-Ø-2	9	66	850	4108	38	264	540	6416
21	3				275	4383	8	272	1120	7536
22	13	6-G/C-1, 6-G-3, 6-H-1, 6-Ø-6	18	84	25	4408	1	273	25	7651
23	24				30	4438	1	274	7	7568
24	25				35	4473	2	276	24	7592
25	28	6-AF-5	4	88	850	5323	38	314	540	8132
26	15				34	5357	1	315	5	8137
27	17				24	5381	1	316	15	8152
28	22				45	5426	2	318	60	8212
29	26	6-M-1, 6-M-6	10	98	70	5496	2	320	30	8242

Table 5-14

SENSITIVITY ANALYSIS WORKSHEET - STRATEGY 2

STRATEGY: ADD INSTRUMENTS IN DESCENDING ORDER OF THE NUMBER OF RESEARCH CLUSTERS IN WHICH USED

Step	Instr Added	Research Cluster Added	No. of C.I.		Instr Wt (lbm)	Cum Wt	Instr Vol (ft^3)	Cum Vol	Instr Pwr (W)	Cum Pwr
			RC	Cum						
1	18				750	750	7	7	1800	1800
2	7				150	900	12	19	-	1800
3	9				60	960	1	20	100	1900
4	2				300	1260	21	41	780	2680
5	12				150	1410	6	47	-	2680
6	1				-	1410	-	47	-	2680
7	10				11	1421	-	47	8	2688
8	8				250	1671	4	51	-	2688
9	19				300	1971	19	70	190	2878
10	16				200	2171	10	80	25	2903
11	5	6-H-6	2	2	40	2211	1	81	150	3053
12	13				25	2236	1	82	25	3078
13	27				850	3086	38	120	540	3618
14	14	6-H-5	4	6	620	2706	112	232	2500	6118
15	3	6-G/C-1	1	7	275	3981	8	240	1120	7238
16	21	6-H-1, 6-Ø-3	15	22	13	3994	1	241	6	7244
17	29	6-Ø-5	4	26	-	3994	1	242	-	7234
18	20	6-Ø-4	10	36	75	4069	1	243	130	7374
19	6	6-Ø-2, 6-Ø-6, 6-Ø-7	19	55	200	4269	24	267	-	7374
20	4	6-G-3, 6-H-2	9	64	87	4356	2	269	163	7537
21	11	6-M-2	6	70	22	4378	3	272	6	7543
22	24				30	4408	1	273	7	7550
23	25				35	4443	2	275	24	7574
24	23	6-M-5, 6-Ø-1	14	84	30	4473	1	276	18	7592
25	15				34	4507	1	277	5	7597
26	17				24	4531	1	278	15	7612
27	22				45	4576	2	280	60	7672
28	26	6-M-1, 6-M-6	10	94	70	4646	2	282	30	7702
29	28	6-AF-5	4	98	850	5496	38	320	540	8242

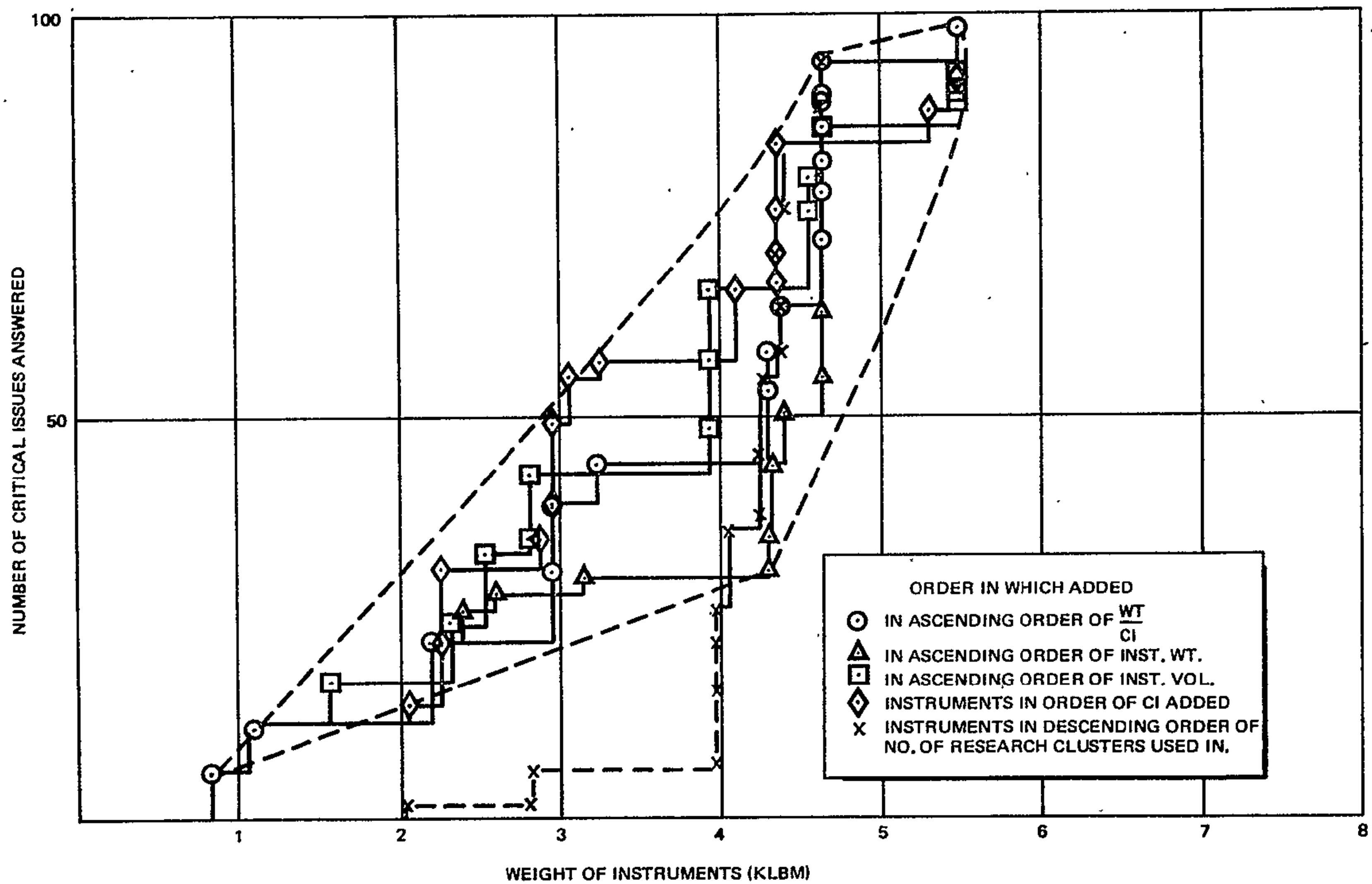


Figure 5-49. Earth Observations Critical Issues Answered Versus Instrument Weight

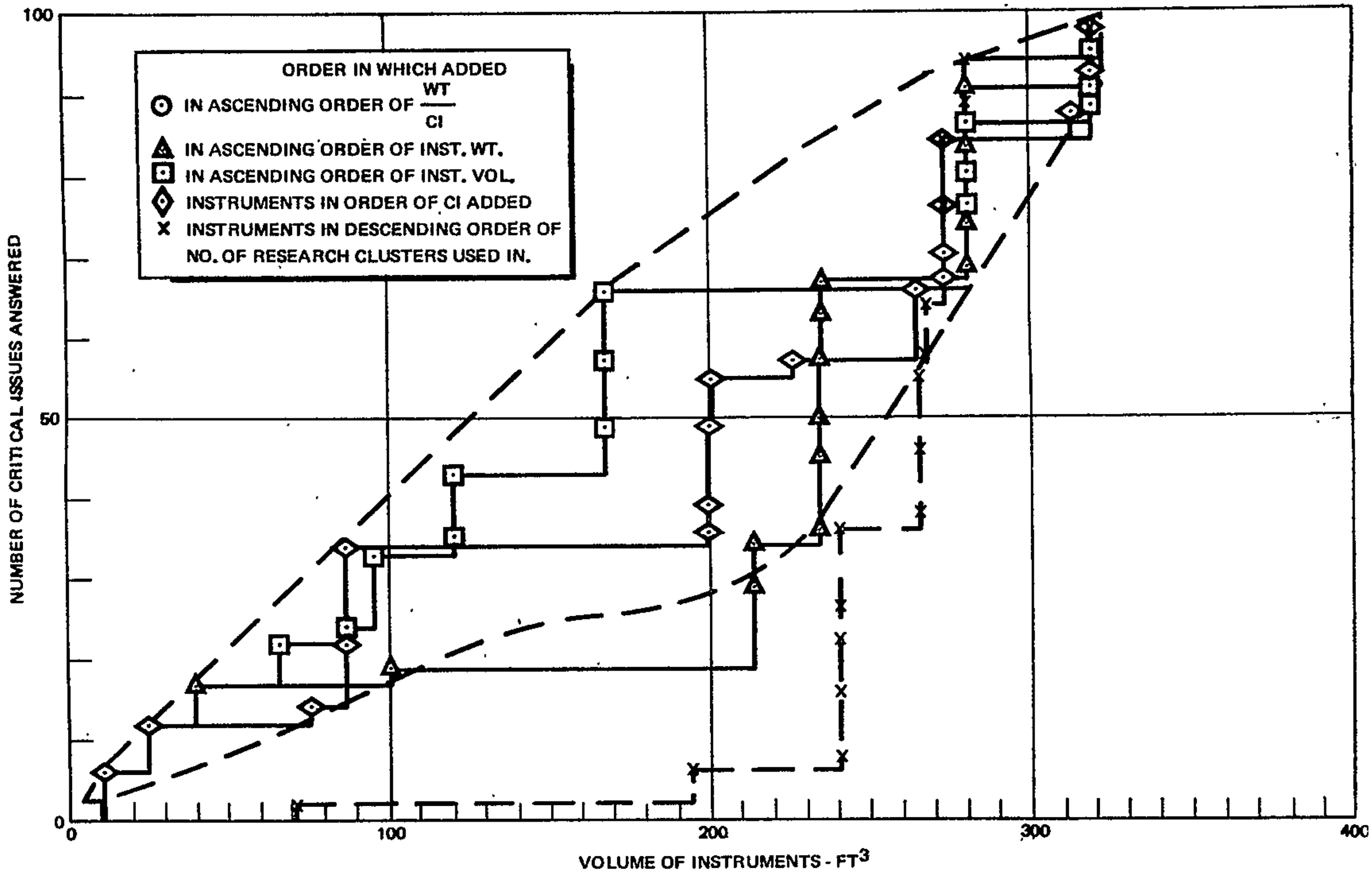


Figure 5-50. Earth Observations Critical Issues Answered Versus Instrument Volume

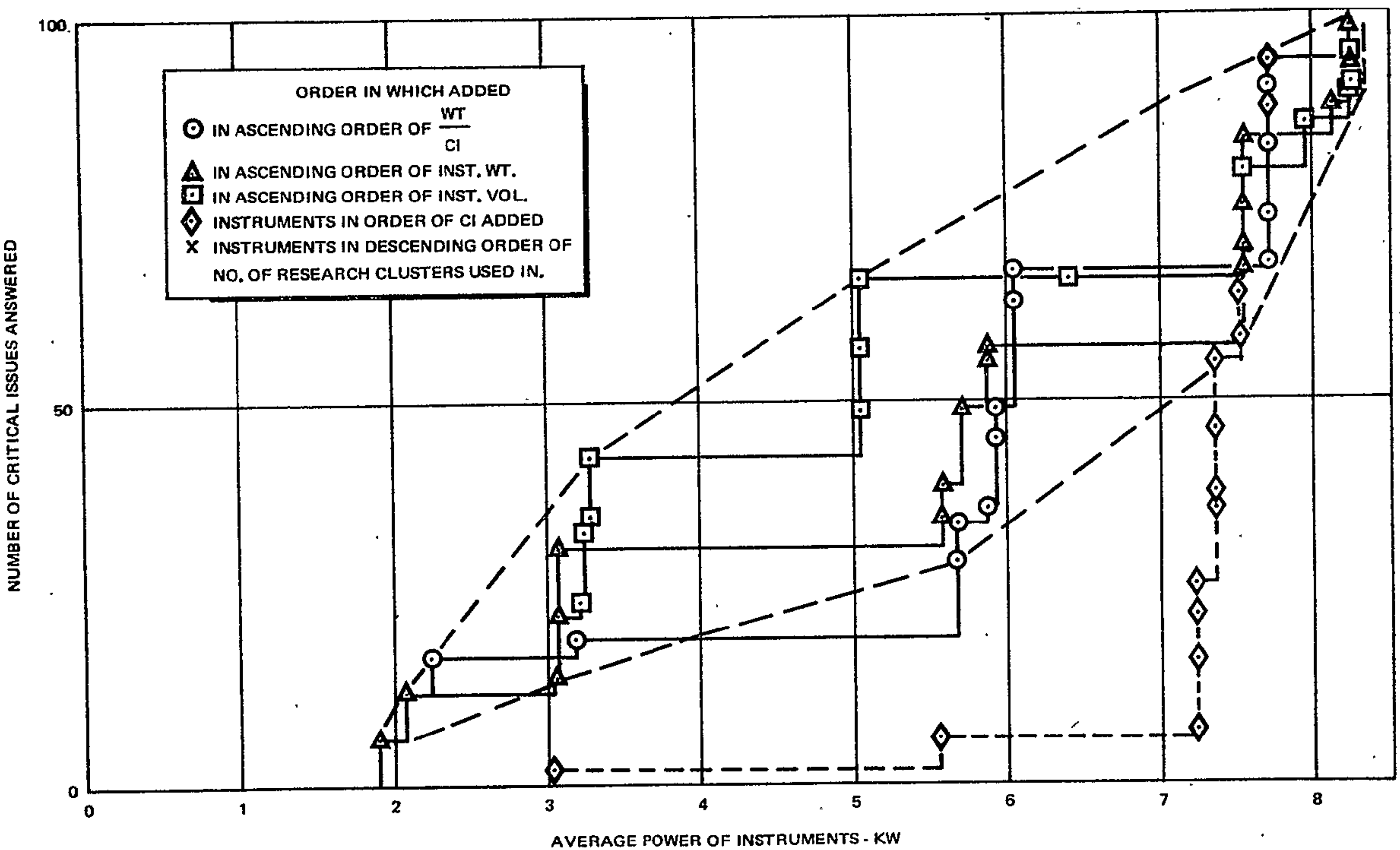


Figure 5-51. Critical Issues Versus Instrument Average Power

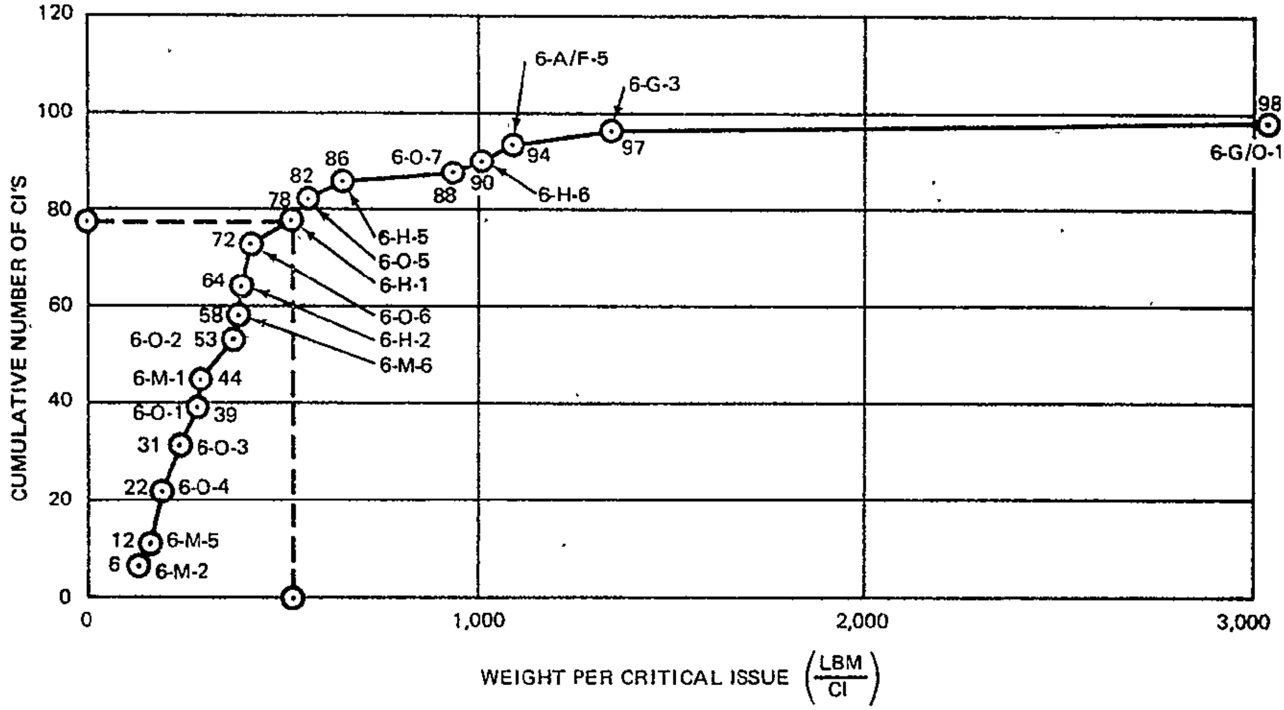
5.7.3 Sensitivity Analysis Technique

If an iteration is required in the mission planning process to either raise or lower the space station size demand, the planner will want to know how sensitive his selected set of research clusters is to the addition or deletion of each individual research cluster. His decision will encompass a recognition of the influences of experiment weight, volume, or power as well as crew limitations.

5.7.3.1 Weight, Volume, and Power

To illustrate sensitivity influences in the 18 Earth Observations research clusters selected, the earlier data were reviewed to determine cluster rank, in terms of weight and volume per critical issue. The results of this review are shown in Figure 5-52, which is plotted as an ordered set with the respective ascending ranks of the research clusters. When these two rankings were compared with each other, it was found that the first eight research clusters (6-M-1, 6-M-2, 6-M-5, 6-M-6, 6-0-1, 6-0-2, 6-0-3, and 6-0-4) shared a common low ranking. The slope, CI/lb or CI/ft^3, is an indication of the gain in information for each pound or cubic foot of payload. That is, these eight research groups were characterized by having a relatively high return (60 percent) on 58 critical issues answered for their investment in either weight or volume.

To exemplify the sensitivity aspects, these eight clusters were assumed to establish a baseline minimum payload set already accepted to go on the hypothetical mission. The planner, then, wants to know which of the remaining ten clusters should be added to get the most information return for this incremental investment. A series of graphs, Figure 5-53 through 5-56 provide a ready means of answering that question. These figures show the relative gain of adding any one of the ten remaining clusters to the basic eight. To facilitate the summing of weight, volume, and power data in this mission planning example, a simple computer program (Table 5-15) was written. Its purpose is to manipulate a file in which is stored information on the number of critical issues, and to order or rank the subsets of instrument weight, volume, and power associated with each research cluster when each are uniquely included.



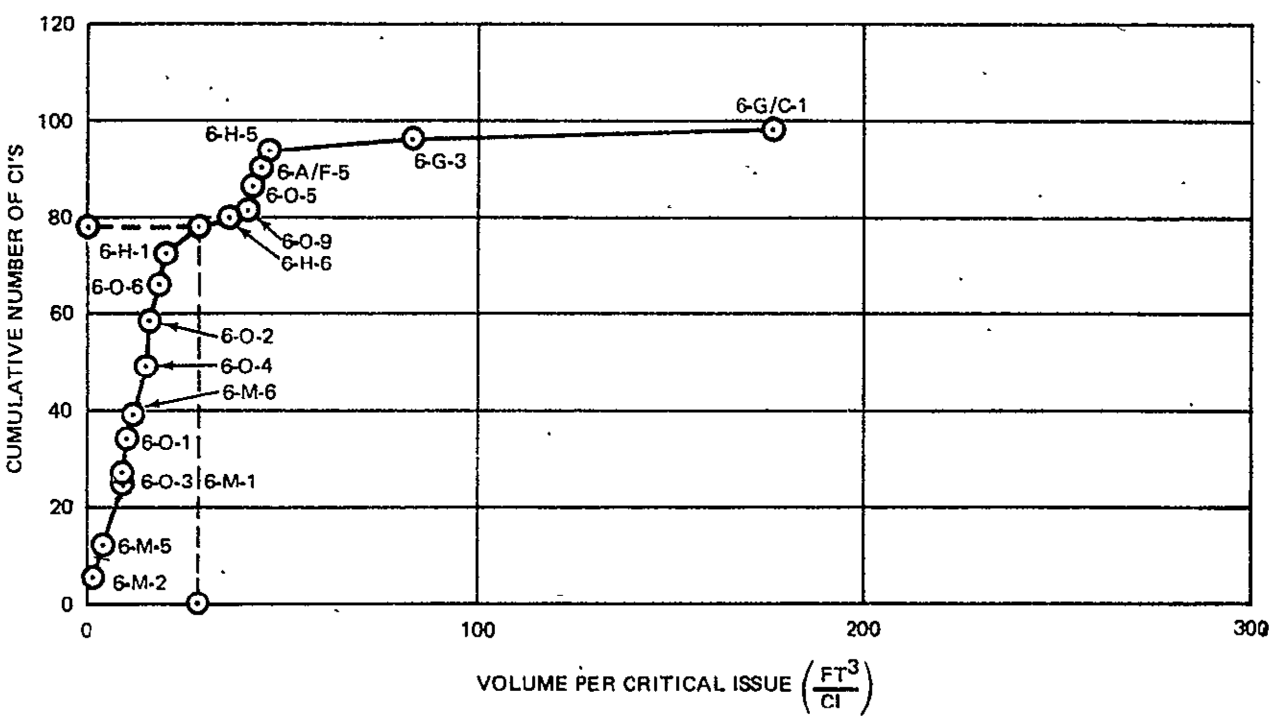
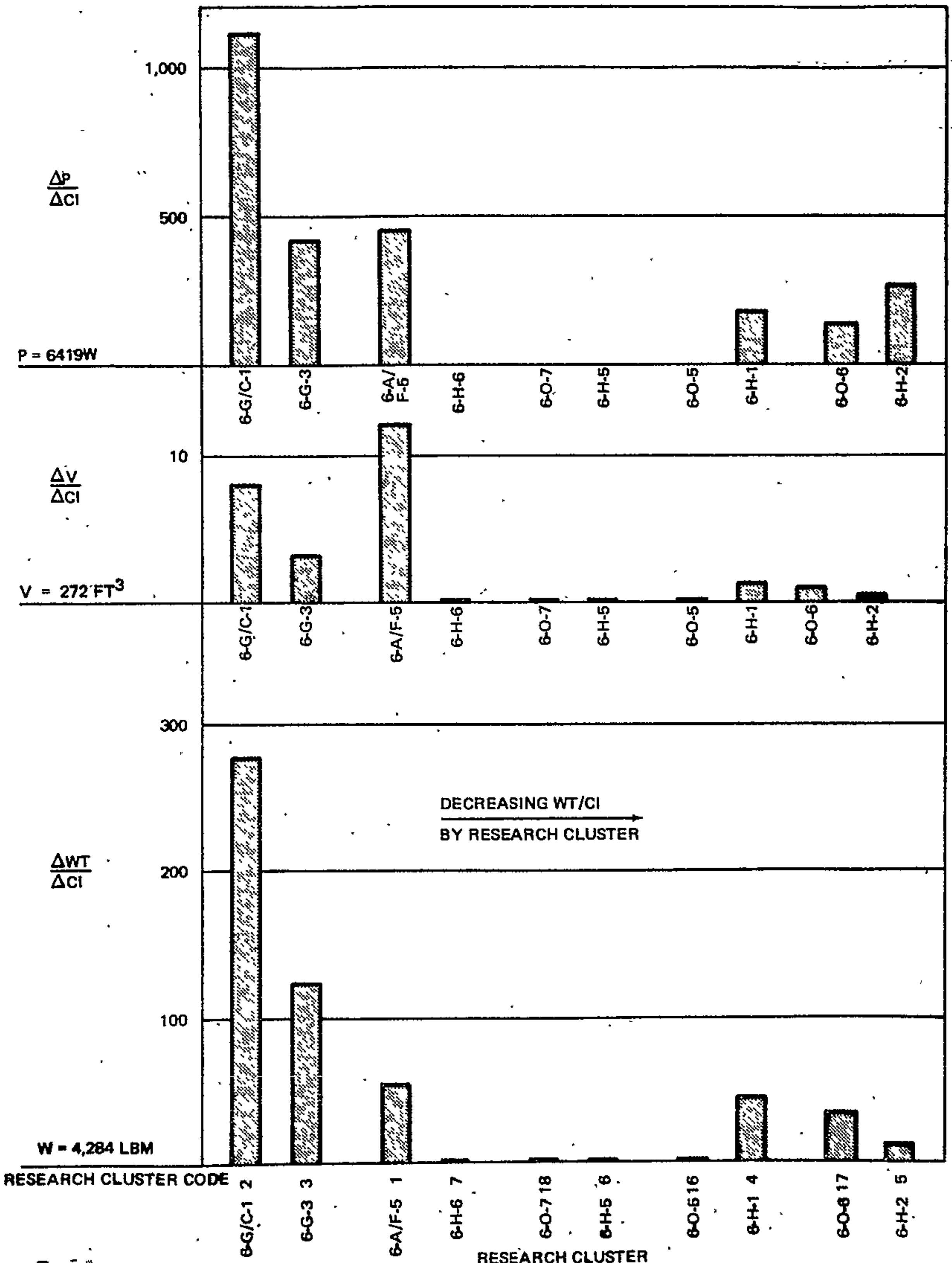


Figure 5-52. Sensitivity Analysis-Weight and Volume



5.53

Figure 5-53. Sensitivity at 58 CI Base

C-8

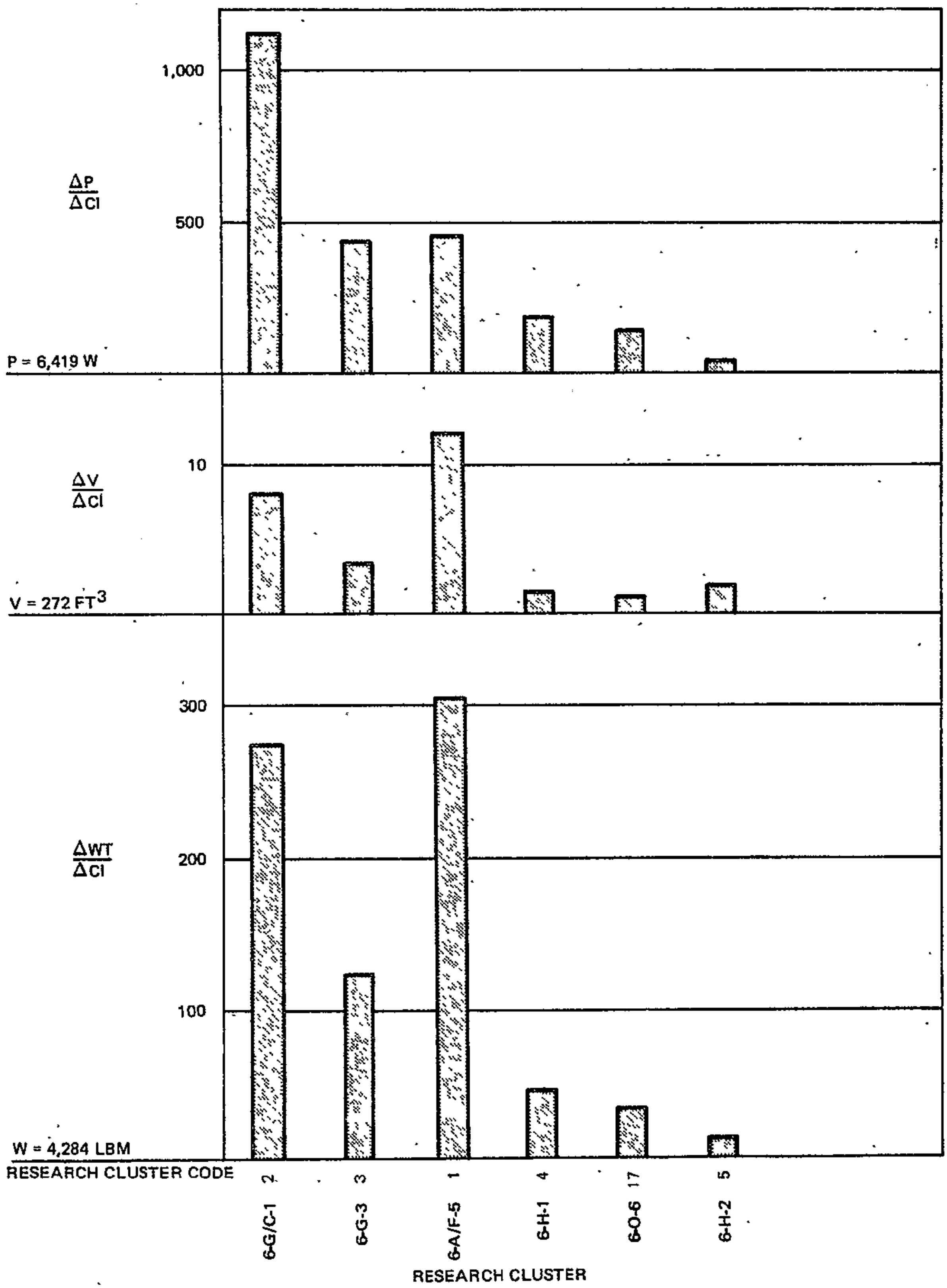


Figure 5-54. Sensitivity at 70 CI Base

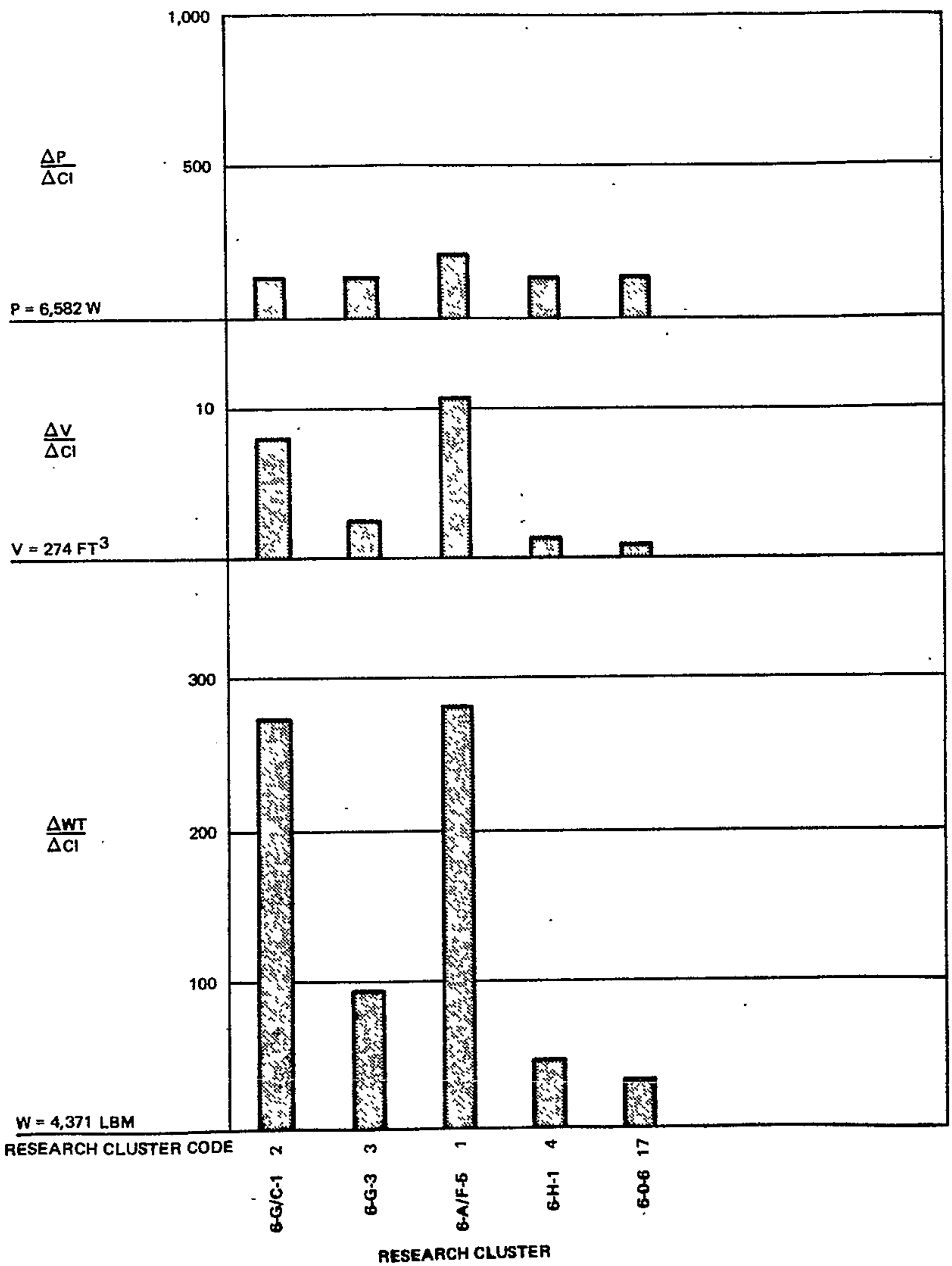


Figure 5-55. Sensitivity at 76 CI Base

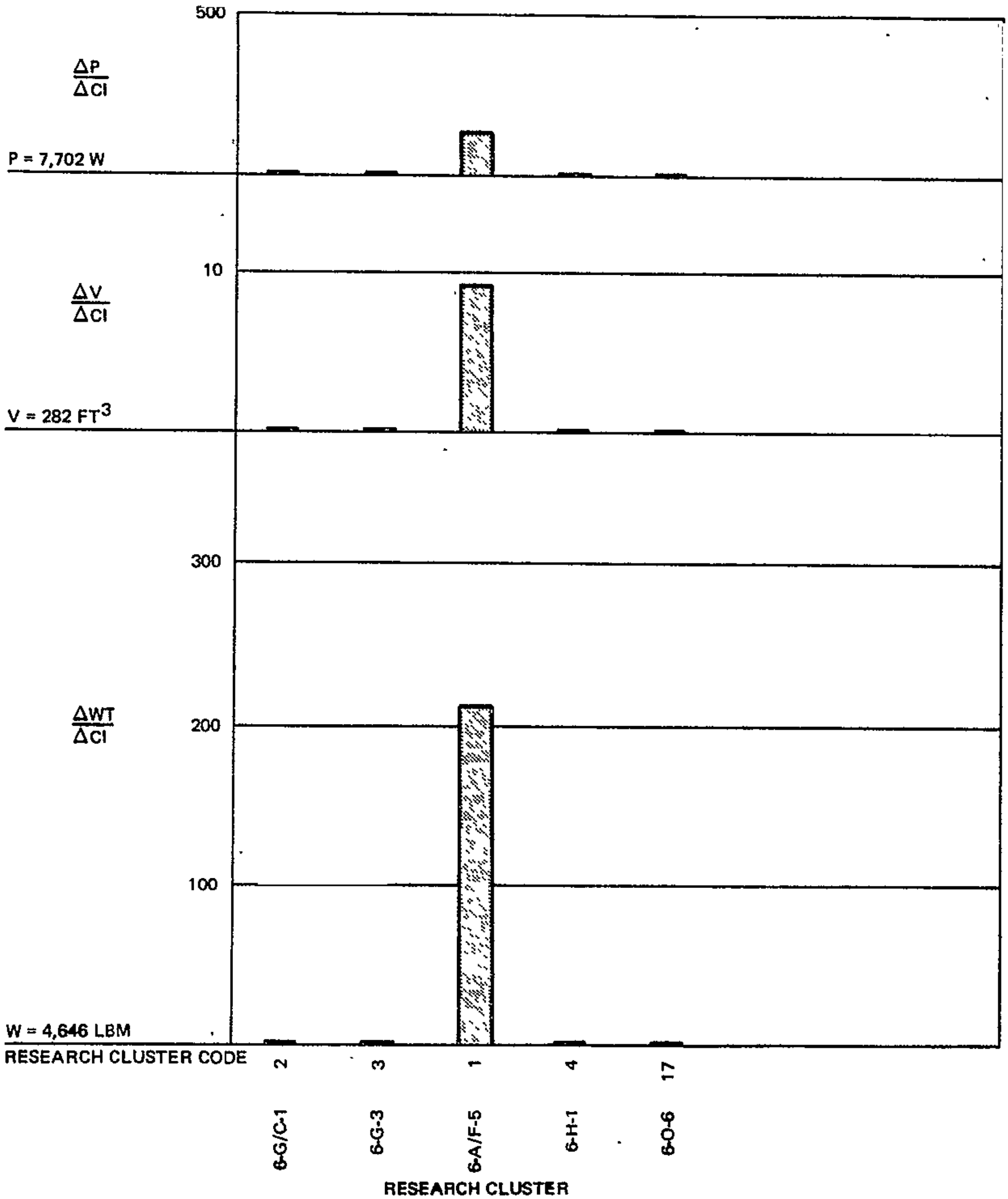


Figure 5-56. Sensitivity at 94 CI Base

Table 5-15

DATA MANIPULATION PROGRAM - EARTH OBSERVATIONS

```
1ϕ INTEGER C(18), I(18,29), W(29,3) J(29), S(3), D(18)
2ϕ OPEN /SD6/, INPUT, 1
3ϕ MAT INPUT FROM 1:C
4ϕ MAT INPUT FROM 1:I
5ϕ MAT INPUT FROM 1:W
6ϕ GO SUB 5ϕϕ
7ϕ PRINT "RC NUMBER"
8ϕ INPUT E
9ϕ IF E # ϕ THEN 11ϕ ELSE GO SUB 5ϕϕ
1ϕϕ GO TO 7ϕ
11ϕ IF E < ϕ THEN 16ϕ
12ϕ IF D(E) = 1 THEN 7ϕ ELSE D(E) = 1
13ϕ GO SUB 6ϕϕ
14ϕ PRINT CS;S(1);S(2);S(3)
15ϕ GO TO 7ϕ
16ϕ D(-E) = ϕ
17ϕ GO SUB 51ϕ
18ϕ GO SUB 6ϕϕ IF D(E)=1 FOR E=1 TO 18
19ϕ GO TO 14ϕ
5ϕϕ MAT D = ZER
51ϕ MAT J = ZER
52ϕ MAT S = ZER
53ϕ CS=ϕ
54ϕ RETURN
6ϕϕ FOR A = 1 TO 29
61ϕ IF I(E,A)<=J(A) THEN 64ϕ
62ϕ J(A) = I(E,A)
63ϕ S(B) = S(B) + W(A,B) FOR B = 1 TO 3
64ϕ NEXT A
65ϕ CS = CS + C(E)
66ϕ RETURN
```

DEFINITIONS

C(18)	An 18-by-1 matrix that identifies each research cluster by a number, 1 through 18.
I(18,29)	An 18-by-29 matrix that identifies in the form of a truth table the instruments that each research cluster requries.
W(29,3)	A 29-by-3 matrix that identifies the weight, volume, and power associated with each instrument
J(29)	A 29-by-1 matrix that stores data on whether or not a given instrument has been added in this run.
S(3)	A 1-by-3 matrix that stores the summations of weight, volume, and power.

D(18)	A 1-by-18 matrix that stores data on whether or not a given research cluster has been added in this run.
E	The number of the research cluster being added.
-E	The number of the research cluster being taken out.

To use this program, a planner inputs the code number of the research cluster and reads in data to be added to a mission payload list. (If it is desired to remove a research cluster from the payload, the coded number is given a negative sign.)

By use of this program, the eight clusters which compose the minimum set were increased by adding to the values obtained one-by-one out of the remaining clusters. The sensitivity of weight, volume, and power demands exceeding the baseline for each of the remaining ten clusters is plotted in Figure 5-53. The baseline values shown at the left of the abscissa are the weight, volume, and power which are required by the selected set of research clusters. The vertical bars indicate how much the addition of a given research cluster increases weight, volume, and power of the required instruments expressed as a ratio of the number of additional critical issues answered by the new research cluster to the selected parameter. For example, in Figure 5-53, research cluster 6-G/C-1, if added to the basic set of eight, would increase the weight requirement of instruments from 4,284 lbm by 275 lbm/critical issue answered. Similarly, the volume requirement would increase by 8 ft^3/ critical issue added, and the power requirement by 1100 watts/critical issue added.

Figures, 5-54 through 5-56, illustrate the changes in sensitivity of the basic set of the remaining research clusters. The procedure used in selecting the research clusters to be summed is to add those which give the most return in critical issues answered for the least cost in weight. Volume, or power could also be chosen, depending upon the desire of the planner. Referring to Figure 5-53, since 6-H-6, 6-0-7, 6-H-5, and 6-0-5 all may be included without an increase in the instrument weight demands, they were added. This raised the threshold to 70 critical issues. Figure 5-54 presents the sensitivity of the new base of 70 critical issues answered to each of the remaining research clusters. It shows that 6-H-2 would be the next candidate to be added with the least penalty on a basis of weight. With 6-H-2 added to the base, 76 critical issues would now be resolved. The new sensitivities are shown in Figure 5-55. This ordering procedure was continued through the base of 94 critical issues with the final graph, Figure 5-56, indicating that 6-A/F-5 is the last research cluster to exceed the weight, volume, and power thresholds. This information is valuable to the planner who is faced with a research selection decision constrained by payload weight, volume, or power.

5.7.3.2 Crew Analysis

Crew mixture and task estimates were prepared as a part of the descriptions for each of the 136 research clusters. The worksheets used for these estimates provide the basic reference material for conducting a crew analysis. Table 5-16 is a typical worksheet example and indicates the frequency of occurrence for each task described and the minutes of task time. In performing the calculation leading to a prediction of weekly or yearly totals, the average value was used when a range of task times was stated. Each crew task has been assigned a reference skill code number and skill level as defined in Table 5-17, in addition to a code for the type of activity involved. A first day time-line estimate was calculated for the above example and is presented in Figure 5-57.

In assessing crew requirements to support the example mission, eight crew skills were identified in the research clusters chosen for Earth Observations. These eight skills are:

Skill Code ( )

- Engineering (5)
- Oceanography (8)
- Forestry (9)
- Geology (11)
- Meteorology (12)
- Cartography (14)
- Hydrology (15)
- Astronaut (21)

RESEARCH CLUSTER NO. 6-A/F-2

Table 5-16

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY†	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE‡	CREW SKILL†	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION†	TASK CONCURRENCY†
6-A/F-2 -1	Checkout Equipment	All	4	None		5-C	1/wk	15-45	1			
-2	Clean lenses	Sensors	5	EVA		21-B	1/wk	1-2 hrs	1			
-3	Perform onboard preparation (periodic camera focussing, chilldown of IR scanner, prepare optical tracking sensor)	Cameras, IR Scanner	3			5-B	8-10 Orb/wk	30-40	1			
-4	Operate equipment (Operate sensor cycling controls, initiate sequency & duration control)		3			5-B	"	30-50	1			
-5	Visual Observations (Optical scan of target area)		2			9-B	"	20-50	1			
-6	Voice Annotation (record correlative information, optical scan of target area for unusual & potential contributing conditions)	Microphone, audio-recorder	2			9-B	"	30-70	1			
-7	Monitor equipment operation (Sensor associated electronics, camera operation including film advance and data taking equipment operation)		1			5-B	"	30-40	1			
-8	Adjust Equipment (Calibrate cameras & non-imagery sensors using both onboard references and ground-truth signal updates)		1			5-C	3-5 Orb/wk	10-30	1			

†See Legend of Codes, page 5-138. ‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

Table 5-17

LEGEND OF CODES USED IN CREW ACTIVITY MATRIX

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

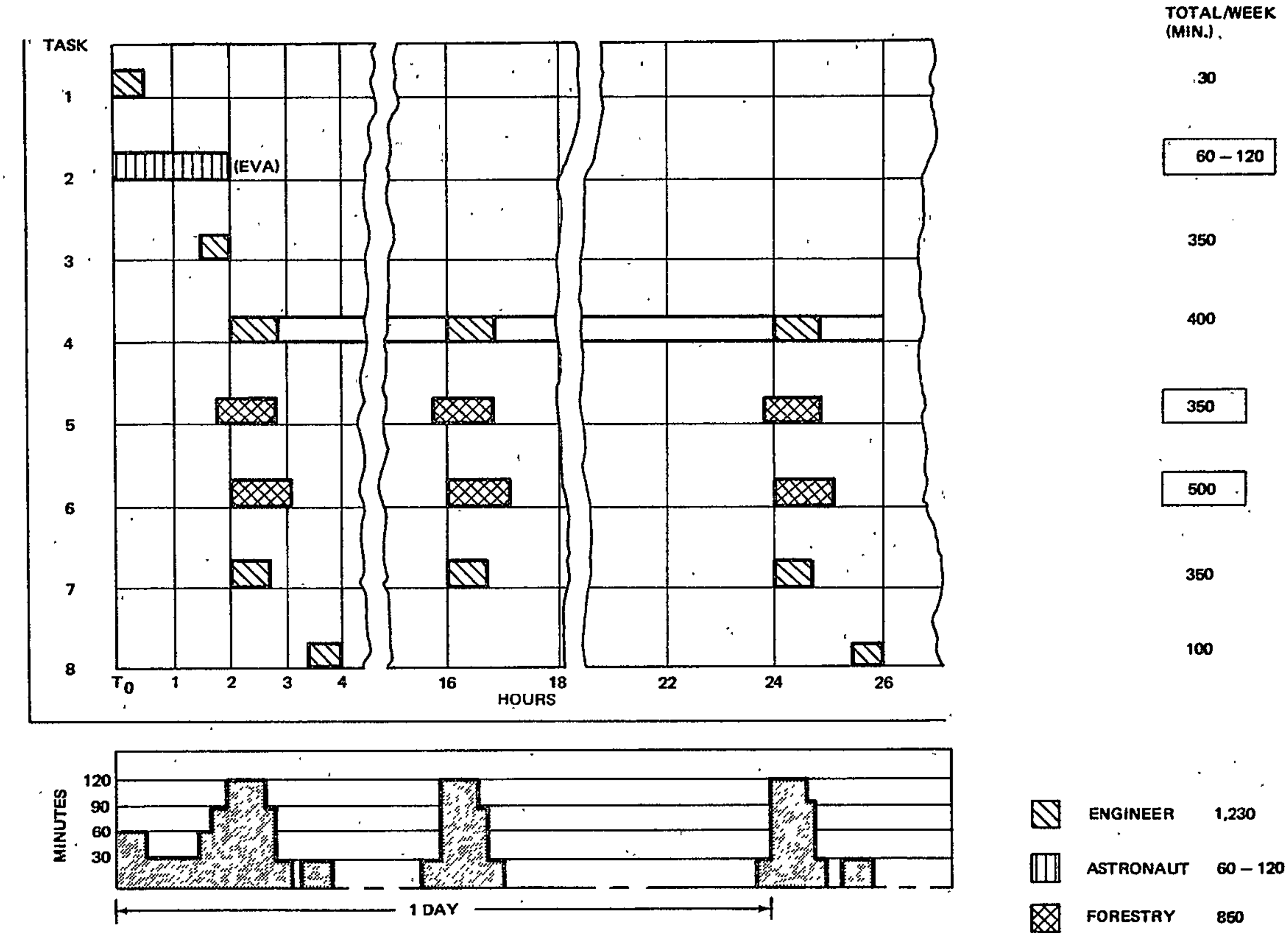


Figure 5-57. First Day 24-hr Crew Time Line (6-A/F-2).

The problem facing the planner is to decide the appropriate crew size for the crew mix specified, and to establish upper and lower limits. If crew hours were simply summed to account for a single skill per crew member, the maximum size could be estimated, and the result might produce an unrealistically high number. Conversely, if the total hours of the mixture of skills was summed and then divided by the maximum hours available from each crew member aboard, a theoretically minimum crew size is obtained. Since, in reality, some measurement tasks have to be done only once to satisfy all of the similar measurements providing data for other research clusters, an integration of estimated crew times is possible. The procedure used is described in the following paragraphs.

For each of the 18 research clusters selected, by using the mission screening procedure, various crew skills and average weekly hours were estimated. The process involved a calculation of average task times for each skill level and type, multiplied by the average frequency of occurrence. The total times-per-week per skill and skill level were summed for each experiment. A worksheet shown as Table 5-18 was then prepared to reflect the measured parameters and instrumentation appropriate to each experiment. No distinction was made between skill levels for this work. At this point, an assumption was applied that any measurement using an item of equipment for one research cluster was sufficient to meet requirements of data for another cluster where duplication of the common measurement and equipment was indicated. Any new parameter or instrument provides an incremental adjustment to the total. This approach permitted an estimate which presents a more acceptable position for mission planning.

Several points of departure indicated in the worksheet need explanation. First, the crew tasks were inspected to determine whether the required skill was predominately instrumentation-oriented or required a signal analytical capability. It was found that the astronaut skill (21) was used in equipment erection and for cleaning lenses of sensors. The relatively few hours shown when EVA was necessary will attest to this circumstance. In the case of engineering (5) skills, the preparation and operation of equipment are a major task. Therefore,

Table 5-1[illegible]
WORKSHEET I, CREW ANALYSIS EARTH OBSERVATIONS

Group No.	Engineer (5) Δ		Oceanography (9) Δ		Forestry (9) Δ		Geology (11) Δ		Meterology (12) Δ		Cartography (14) Δ		Hydrology (15) Δ		Astronaut 21 Δ		Year Total
6-A'F-5	[illegible]	10.0			3.0	3.0									1.5	1.4	754
6-G/C-1	-	11.0									6.0	6.0			-	1.5	952
6-G-3	18.5	24.5					20.0	20.0							15	1.5	2396
6-H-1	1.0	2.0											37.0	37.0	15	1.5	2055
-2		10.0											7.4	24.0	-	2.0	1881
-5		13.5											22.2	5.0	-	1.5	1041
-6	-	8.0											14.8	14.0		1.5	1221
6-M-1	48.5	50.5							11.7	11.7					-6	2.0	3330
-2	-	7.1							3.9	25.0					-		1669
-5									3.9	7.3			7.4	30.0	15	1.5	2027
-6	-	50.5							-	12.5					-	1.5	3354
6-O-1			18.5	18.5									7.4	30.0	-	1.5	2608
-2			6.2	4.5									14.8	23.5	15	1.5	1544
-3			3.1	7.5									7.4	34.0	-	1.5	2288
-4			-	7.5									-	24.5	-	1.5	1729
-5													14.8	31.0		1.5	1691
-6			-	7.0									-	22.0	-	1.5	1594
-7			-	4.75									-	22.0	-	1.5	1679
Σ	78.1	186.1	27.5	53.25	3.0	3.0	20.0	20.0	19.5	56.5	6.0	6.0	133.2	297.0	2.85	26.5	

Measured Parameters

Group No. Clusters	Smoke Pall or Plume	Vegetation Stress Due to Drought	Active Fires	Sleeper or Small Fires	Sferics	Physical/Cultural Features - Global	Erosion, Subsidence Fracture Snow Melt	Thermal Anomalies Volcanic	Structural Geology	Surface Features Damage	Areal extent, Tonal Contrast, Clouds	Sediment Spectrum, Plant and Water	Organic Pollution	Multispectral Data	Thermal Pollution, Water Circulation	Soil Moisture and Precipitation	Soil Types Texture, Water, Permafrost	Surface Temp Patterns of Terrain	Terrain Brightness T°	Vegetation Spectral Characteristics	Water Spectral Radiance	Atmos Gas Spectral Profile NO_2/SO_2	Sea Surface T°	Sea Color	Precipitation	Surface Mean Height	Ice Surface Temperature	Sea Surface Salinity	Δ Parameters	Δ Instruments
6-A'F-5	X	X	X	X	X																								-	-
6 G/C-1						X																							-	-
6 G-3							X	X	X	X																			-	+1
6 H-1											X	X	X	X	X														-	+1
-2											X					X													+1	-
-5																	X	X	X										-3	-
-6															X					X	X								+2	-
6-M-1											X									X	X								-	-4
-2					X						X																		+1	-
-5																						X							+1	+1
-6					X						X									X	X								-	-
6-O-1						X					X	X			X					X			X						+1	-
-2						X					X							X					X	X	X				+2	+1
-3						X					X									X			X	X		X			+1	-
-4											X																			-
-5																							X				X	X	+-	-
-6											X	X			X														-	-
-7						X					X																		-	-

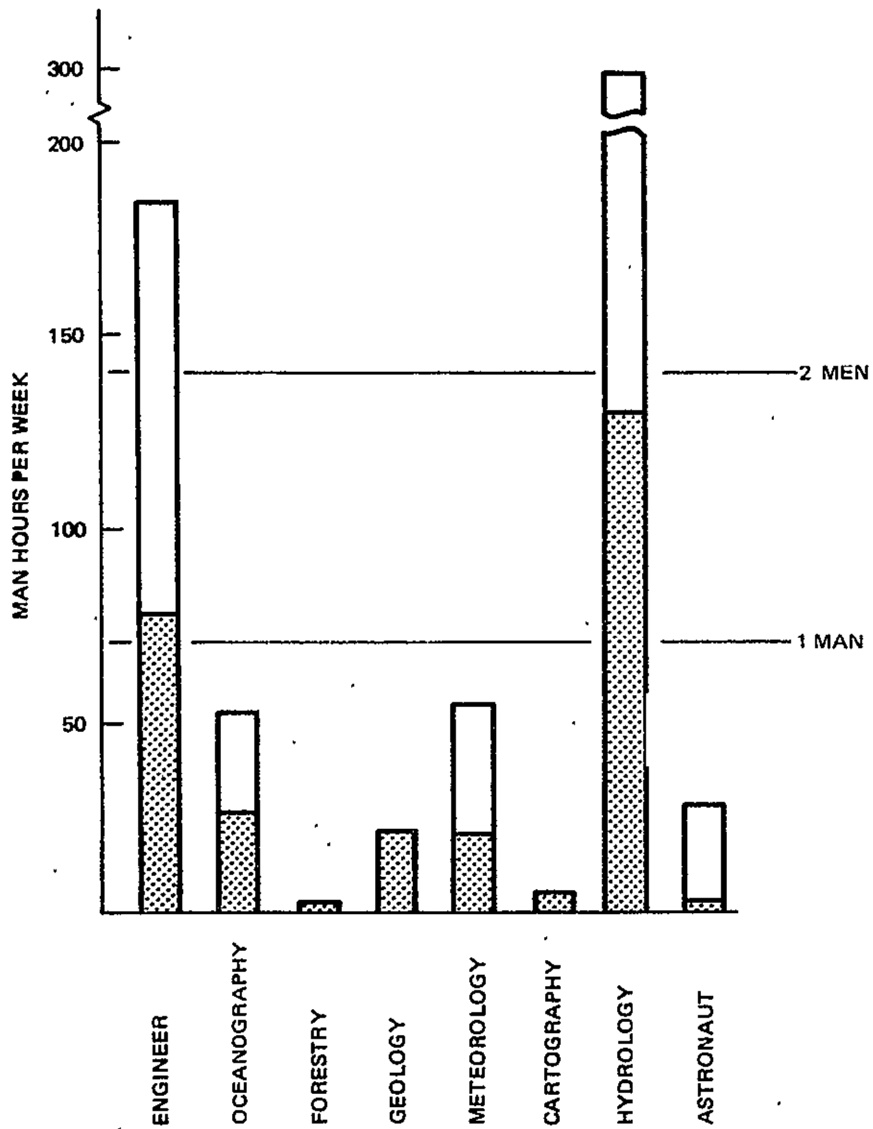
Instruments

Group No. Clusters	Metric Camera	Multispectral Camera	10 Band Multispectral Scanner	Radar Imager	Absorption Spectrometer	Multichan Ocean Color Sensor	Radar Altimeter/Scatterometer	Microwave Scan Radiometer	Sferic Det UHF	Data Collection Sys	Photo Imaging Camera	IR Interferometer	Multispect Tracking Telescope	Selective Chopper Radiometer	IR Filter Wedge Spectrometer	IR Temp Sounder	Satellite IR Sounder	Temp Profile Radiometer
6-A'F-5	X	X	X					X	X	X	X	X	X		X			
6 G/C-1	X	X	X															
6 G-3	X	X	X	X				X		X	X							
6 H-1	X	X	X			X				X								
-2	X			X				X		X	X							
-5	X		X	X				X		X								
-6	X		X							X								
6-M-1												X		X	X	X	X	X
-2									X									
-5					X													
-6	X								X			X		X	X	X	X	X
6-O-1	X		X		X	X		X		X								
-2	X		X			X	X	X		X								
-3	X		X			X		X		X								
-4	X			X			X			X								
-5	X			X				X		X								
-6	X	X	X				X			X								
-7	X						X	X		X								

a proration of 0.15 hours was used for each new instrument listed (based on dividing the 1.5 hours by 10, the number of instruments used in the 6-A/F-5 research). However, since observations and analysis of data seemed to predominate the earth scientist skills, a distribution of hours based on a prorating of the measured parameters was applied for these specialty skills. Only in the case of the hydrologist did this pose any particular problem. It should be noted that the hydrologist skill is shown not only for research in Hydrology but also in Meteorology and Oceanography. Therefore, man-hour increments were prorated across the three research areas named and only added when new parameters were indicated. Referring to the worksheet, the initial estimates (6-H-1) of hydrologist hours was accepted as being about 33 hours across five parameters, or an average of over 6-1/2 hr per measurement. For each new parameter, an additional increment of 6-1/2 hr was added. The sums of all skills and hours per week were then totaled as illustrated in Figure 5-58.

In following the calculations shown on the worksheet for this analysis, a few concessions made are in prorating crew hours. A case in point is found in meteorology, where similar measurements are indicated for other research but not on the global scale specified for 6-M-1. The required instrumentation is also somewhat different. For these reasons, the entire 92 hours per week of engineering skill was allowed for 6-M-1. However, since 6-M-6 also specified this instrumentation and would need data apparently duplicated by the other meteorological research, its crew requirements of 101.5 hours were not added to the other three experiments in Meteorology.

In the case of this particular body of research, it was found that considerable measurement duplication was present. This conclusion is shown in Figure 5-59. By directly summing the various skills and assuming a crew member for each skill, even though specialists are not fully utilized, the maximum crew size for experiment purposes is fourteen. The predominant demand on skills are hydrology with five members and four for engineering. Crew size based on integrated total hours for each cluster, assuming a mixture of skills so as to obtain maximum use of each crew member across one or more specialties, reduces this number to approximately 10 men. Also, by combining common parameters and



SKILL	HR. (SUM)	HR. (INTEG)
5	186.1	78.0
8	53.3	27.8
9	3.0	3.0
11	20.0	20.0
12	56.5	19.5
14	6.0	6.0
15	297.0	133.2
21	26.5	2.9
Σ	648.4	270.4

Figure 5-58. Crew Skills-Earth Observations

instruments, but now allowing mixed specialties of crew, the total reduces from 14 to 10 scientific crew members. If one assumes both combined skills and combined parameters and instruments, a minimum crew size of 4 is estimated. The results found by following the procedure seem to indicate that a reasonable crew size would fall between 6 and 8, with the assumption that two or more of the required skills are available from several of the crew members. This analysis also suggests that preferred selection criteria and even training requirements covering several skills could be forecast in the early stages of mission planning.

A second set of data is shown in Table 5-19. Utilizing the crew estimates substantiates the above analysis and tends to identify another rather significant feature. The procedure followed was to calculate the yearly man-hour estimate for each research cluster, since the term of research was defined as 1 year, and then to prepare a sensitivity plot similar to those for weight, volume, and power. By dividing the man-hour estimate by the number of critical issues, an information-gain factor was obtained for each experiment description in terms of the number of hours to be invested per critical issue. These data were then ordered from the least number to the greatest by research cluster, and the resultant graph is shown in Figure 5-60. The figure was replotted in a cumulative plot of total man-hours per critical issue, shown in Figure 5-61. Although these data do not discriminate among different skills, as the former analysis did, it may be seen by the lower scale that over 80 percent of the critical issues in Earth Observations may be answered with a cumulative investment of less than six crewmen per year. This graph data again assumes multiple skills available from crew members but disregards any synergistic effects from common measurements. The man-year number used was based on a 52-week year at 70 hours per crew member per week.

5.7.4 Data Characteristics

The selected payload groupings being analyzed in the mission example consist of experiments representing the Earth Observations category. For purposes of data management, system analysis, and concept formulation, these experiments also represent the most difficult requirements found in any payload grouping.

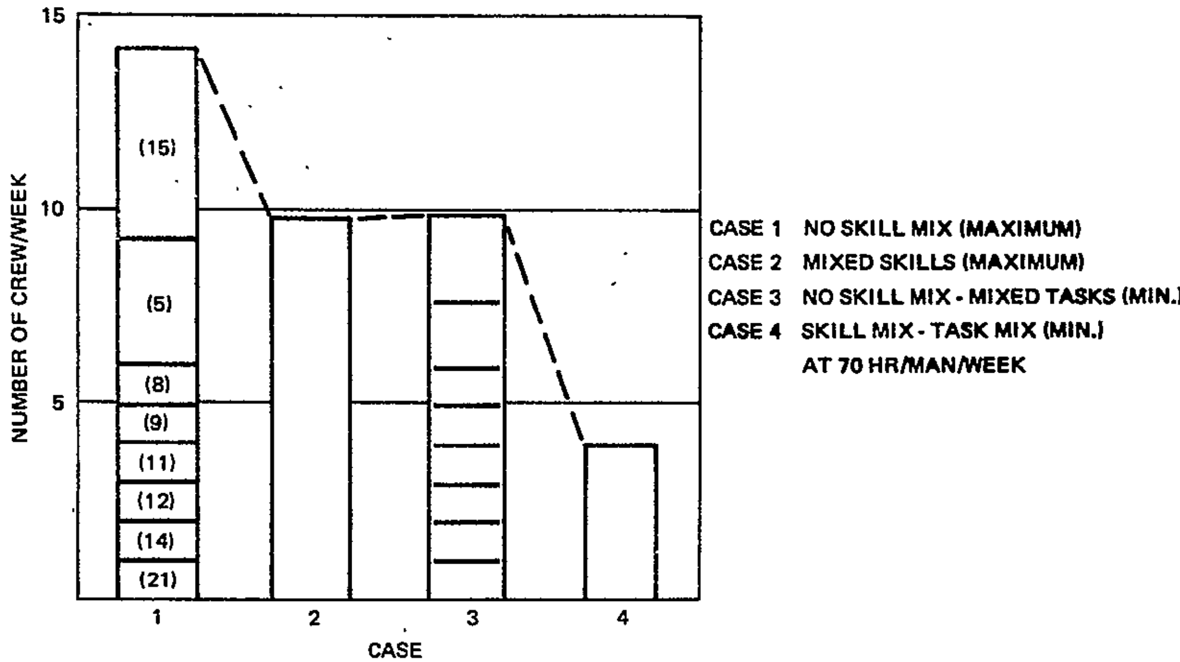


Figure 5-59 Crew Analysis—Earth Observations

Key information management considerations presented by the experiments in the grouping include observational data with man as the detector and direct interface with the experiment variables, high-volume data sources, high-rate data sources, image data sources, complex control problems, and broad areas requiring crewman evaluation of data on a real-time or near-real-time basis. Complex experiments may also require, in the absence of needed skills, a considerable degree of ground involvement in both the control and the preliminary evaluation of data collected. Ground involvement will also be recognized for in-orbit experiments that require simultaneous control experiments to be conducted on the ground, and also experiments requiring truth-site data to be collected concurrently with remotely sensed data.

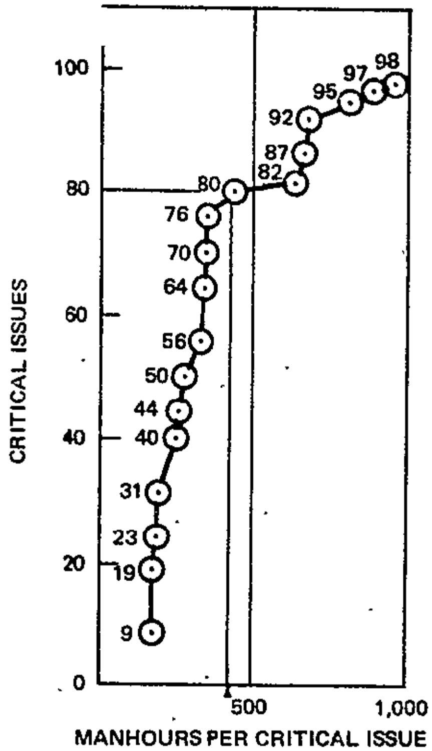
Experiment activities and equipment listed in the 136 research cluster descriptions represent more support requirements than any single mission can provide, even such a long-duration mission as that foreseen for the Space Station. Criteria for selection and screening consider such factors as the general programmatic and mission-level restrictions to the more specific and

Table 5-19

WORKSHEET - CREW HOURS

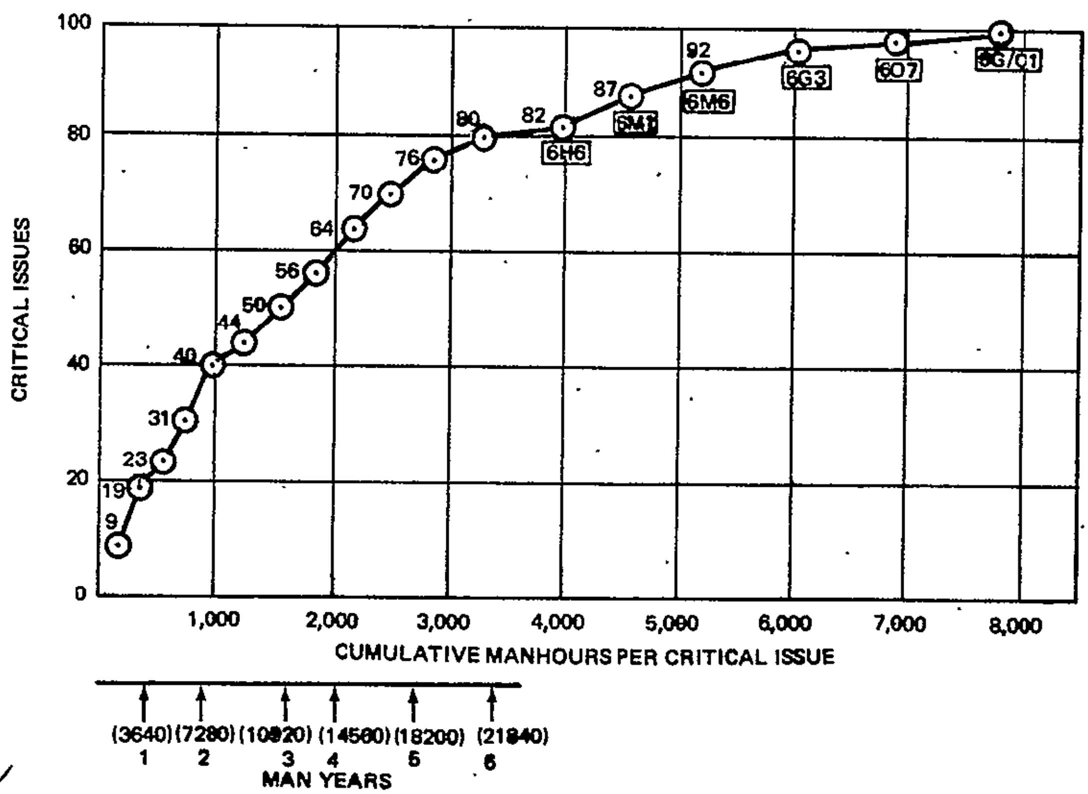
Research Cluster	Yearly Man Hours	Critical Issues	Man Hours per C.I.	Rank
6-A/F-5	754	4	189	3
6-G/C-1	952	1	952	18
6-G-3	2396	3	799	16
6-H-1	2055	6	343	11
6-H-2	1881	6	314	8
6-H-5	1041	4	260	6
6-H-6	1221	2	611	13
6-M-1	3338	5	668	14
6-M-2	1669	6	278	7
6-M-5	2027	6	338	10
6-M-6	3354	5	671	15
6-O-1	2608	8	326	9
6-O-2	1544	9	172	1
6-O-3	2288	9	254	5
6-O-4	1729	10	173	2
6-O-5	1691	4	423	12
6-O-6	1594	8	199	4
6-O-7	1679	2	840	17

Order	Cumulative MH per C.I.	Total Year Cum MH
6-O-2	172	1,544
6-O-4	345	3,273
6-A/F-5	534	4,027
6-O-6	733	5,621
6-O-3	987	7,909
6-H-5	1247	8,950
6-M-2	1525	10,619
6-H-2	1839	12,500
6-O-1	2165	15,108
6-M-5	2503	17,135
6-H-1	2846	19,190
6-O-5	3269	20,881
6-H-6	3880	22,102
6-M-1	4548	25,440
6-M-6	5219	28,794
6-G-3	6018	31,190
6-O-7	6858	32,869
6-G/C-1	7810	33,821



12 OF 18 RESEARCH CLUSTERS FALL BELOW 450 MANHOURS/CI/YEAR FOR OVER 80% OF CI's.

Figure 5-60. Sensitivity to Crew Hours per Critical Issue



5-61

Figure 5-61. Cumulative Crew Hours Per Research Cluster detailed aspects of experiment environment, hazards, and sensitivities. The data management requirements have been analyzed and are summarized in Table 5-20 for the example mission indicated by Table 5-10.

These criteria were applied to obtain a sample experiment set that could be considered for further analysis of requirements and to serve as an example for describing mission and system planning. The important characteristics of each of the research clusters are described in the following summary paragraphs. The various elements making up the data management system are identified so that the planner will be aware of the available system alternatives. Sensor data rates have been estimated for the instruments listed.

5.7.4.1 Detection of Forest Fires (6-AF-5)

Measurements will be taken over areas of incipient forest fire conditions as well as over areas of active fires to determine how well detection, definition, and reporting can be accomplished from space. During the evaluation period, which may extend over several fire seasons, data are collected by ground and airborne sensors while the same data are collected from space for validation and verification.

The following sensors are used in this experiment:

A. Metric cameras (2).
B. Multispectral cameras (6).
C. Microwave scanner radiometer.
D. Multispectral scanner.
E. Sferics detector.
F. Photo imaging cameras (3).
G. Tracking telescope.
H. IR spectrometer.
I. IR temperature sounder.

The data flow expected from the experiment sensors consists of:

A. One-to-three images per target from the cameras (eleven in the group).
B. Electronic data taken continuously while the target is within an acceptable look angle (estimated to be ±30 degrees).

TABLE 5-20

DATA HANDLING AND SUPPORT REQUIREMENTS FOR EXPERIMENTAL CLUSTERS

Research Cluster		Location			Original Data Form									Data Conditioning			Data Buffering				Data Processing					Storage			Display				Control				Support Services					Crew Time			
No.	Title	Integrated	Attached	Free Flying	Hardcopy, Notes	Specimens, Samples	Voice	Film/Plates	Magnetic Tape	Digital	Analog	Video	Remarks	Film Processing Note 1	Analog Electronic Cond.	Digital Electronic Cond.	Pre-DMS	DMS	Digital	Analog	Preprocessing	Redundancy Removal	Evaluation	Computation	Trafficking	Analog	Digital	Physical	Alpha-Numeric	Image	Analog	Special Purpose	Adaptive/Manual	Non-Adaptive/Manual	Remote	Pointing/Stabilization	Environmental Control	Resupply	Onboard Checkout	Rendezvous and Dock	Concurrent Ground	Specialist	Highly-Trained Non-Spec	Non-Specialist	
1-BM	Biomedical	•			•	•	x	•	x	x	•	•	Low Res		•	•	•	x		•	•	•	•	•	•	•	•	•	x	•		•		•	x			•	•	•			x	x	Manned Space Flight Capability
1-BR	Behavioral	•			•		•	x	•	•	•	x	Video or Film		•	•		•	•		•	•	•	•	•	•	•	•	•	•		•		•	x			•		•			x	x	
1-MM	Man's Performance	•			•		•	•	•	•	•	•			•	•	•	•	•		•	•	•	•	•	•	•	•		•			•		•			•						•	
1-LS	Life Support	•			•		•		•	•	•				•	•	•	•	•		•	•	•		•	•	•	•	•					•	•			•	•	•				•	
1-EE	Man and Systems	•		•	•		•	•		•	•			•	•	•	•	•	•		•	•			•		•		•					•	•		•			•				•	
1-EO	Operations	•			•	•	•	x		•	•	x	Video or Film	x	•	•		•	•		•	•	Visual		•		•	•				Visual Analy		•	x	•		•				•		•	
2-IN	Invertebrate Biology	•			•	•	•	•		•	•				•	•		•	•		•	•			•		•	•						•				•	•				x		Space Biology
2-PT	Plant Biology	•			•	•	•			•															•			•	•					•				•	•				x		
4-PC	Space Physics	•			•		•	•		•	•	•			•	•	•		•		•				•		•	•	•	•						•		•	•				•		Space Physics
5-N	RF Noise	•					•	•	•	•	•				•		•	•	•	•					•			•			•	•	•		•		•		•	•				•	Comm and Navigation
5-P	RF Multipath	•					•		•	•	•				•	•	•	•	•		•		•	•	•	•	•		•		•	•	•		•							•		•	
5-TF	Comm-Nav Facility	•					•			•	•	•			•	•	•		•	•	•				•				•			•			•		•	•	•				•		
5-CS	Millimeter Wave Demon.	•					•			•	•				•	•	•		•		•				•		•		•						•		•					•		•	
5-NS	Navigation Systems	•					•		•	•	•	•			•	•	•				•				•	•			•						•		•							•	
6-AF	Agriculture-Forestry		•				•	x		x				x		•	•	•	•	•	•				•		•	•	•	•		•		•	•	•	•		•	•		•		•	Earth Observations
6-GC	Multisensor Map.		•				•	x	•	x				x		•	•		•		•	•			•		•	•						•	•	•	•	•	•			•		•	
6-G	Geology		•		•		•	•	•	•		•		•		•	•	•	•		•	•			•		•	•	•	•				•	•	•	•	•	•					•	
6-H	Hydrology		•				•	•	•	•		•		•		•	•	•	•		•	•			•		•	•	•	•				•	•	•	•	•	•			•		•	
6-M	Meteorology		•				•	•	•	•	•			•	•	•	•	•	•	•	•	•			•	•	•	•	•					•	•	•	•	•	•					•	
6-O	Pollution Monitoring		•				•	•	•	•	•			•	•	•	•	•	•		•				•	•	•	•	•	•				•	•	•	•	•						•	

Note: Onboard Film Processing is not a Firm Requirement. Implementation will Require a Development Effort.

Key: • Low or Medium Requirement
x Significant Requirement

C. Vehicle data for indexing and management of data (location, altitude, look angle, and mission time).

5.7.4.2 Geography-Cartography (6-G/C-1)

High-resolution photographs in black and white and in color will contribute to the updating and correction of geography and mapping of the earth's surface. The activities will also provide essential data on equipment and operations for use in subsequent data collection (possibly unmanned).

Truth sites have already been established to provide a comparison base with known data collected on the ground.

Sensors involved in this experiment include: four metric cameras, boresighted in pairs to give two-film response, and stereo coverage, six multispectral cameras, and multispectral scanner (10-channel).

Data will be collected as conditions of weather and illumination permit. Since full coverage is a requirement, an accounting system will provide coverage control for the mosaic of data being developed.

The areas of coverage have not been specifically defined; however, the following table indicates the minimum number of data sets or photographs required to blanket various areas up to, and including, global coverage.

Multispectral scanner data will also be collected for areas photographed. Scanner data are generated at the rate of 26.4 megabits-per-second.

5.7.4.3 Geology (6-G-3)

Spaceborne sensors will also be directed toward the identification and location of potential geologic hazards. High-resolution observations from space can quickly access the extent of the damage.

Experiment targets will mainly be opportunities caused by geologic events and will be identified by seismic events detected by ground sensors.

The site of geologic uniqueness has been identified as truth sites, e.g., Hawaii, the Cascade Range volcanos, Merapi, Indonesia, Krakatoa, Sumatra, and others. These sites will be observed periodically to establish a data base for developing predictive capability. Sites of active volcanos will be observed on a monthly basis for similar reasons.

The sensors used are metric camera, multispectral camera, multispectral scanner (one channel only), radar imager, microwave scanner, data collection system, and photo imaging camera (three-camera system).

Data characteristics include film from instruments A, B, and D from the above list (the radar imager generating 50 to 150 Megabits per sec that will be recorded on film); broadband electronic data from sensors C and G, with rates up to 2.4 Megabits per sec from a single instrument; and low-rate data on the order of 4 kilobits per second from instruments E and F.

Data collection cycles during initial mission operation will be geared to desired target opportunity, resulting in frequency data collection.

5.7.4.4 Hydrology (6-H-1, -2, -5, and -6)
The principal concern in hydrology is the quantity and quality of fresh-water resources. The experiments are chosen to assess the pollution of coastal and inland waterways from both chemical and thermal sources. The inventory of resources consists of mapping inland waters and temporal observation of snow and ice, and using infrared imagery to locate areas where underground water is being discharged to the surface.

The sensors used provide images in visible, radar, and infrared, as well as multispectral scans.

Data collected from onboard sensors will be compared with data obtained from remotely situated sensor platforms that are interrogated by the space vehicle as it overflys the site, to obtain data for calibration and information that cannot be measured from orbit.

The areas of interest in water resource studies are extensive and will result in a large quantity of data collected. The rate at which data are generated depends on the specific areal requirement and the time allowed for complete observation. Data output characteristics of the sensors used include:

A. Metric camera - 9- by 14-in film
B. Multispectral cameras - 70-mm or 5-in film
C. Multispectral scanner - five channels at 2.4 megabits per sec
D. Radar images - oscillographic recording on film
E. Ocean color sensor - 12 kHz
F. Microwave scanner - five bits per sec (maximum)
G. Data collection system - 256 bits per sec
H. Photo imaging camera - 3.5 MHz (three exposures each 25 sec)

5.7.4.5 Meteorology (6-M-1, -2, -5, and -6)

The instruments used in weather observation are unique to meteorological tasks. However, the importance of weather observation tasks justifies the inclusion of these instruments in the experiment.

Output characteristics are as follows:

A.	Temperature profile radiometer	1,500 bits per sec
B.	Satellite infrared spectrometer	1,260 bits per sec
C.	Infrared temperature sounder	1,000 bits per sec
D.	Infrared filter wedge spectrometer	125 bits per sec
E.	Selective chopper radiometer	48 bits each 15 sec
F.	Infrared interferometer/spectrometer	51.6K bits per sec
G.	UHF sferics detector	300 bits per sec
H.	Metric camera reference frames	9- by 14-in film

5.7.4.6 Oceanography (6-O-1, -2, -3, -4, -5, -6, and -7)

Observation tasks in Oceanography will address the resource potential of the world's oceans, the physical characteristics, and the pollution of its waters. Because of its vastness, and the high rate of changes experienced in its characteristics, this experiment group will result in large quantities of data.

The sensors used and the output characteristics are as follows:

A.	Metric camera	9- by 14-in film
B.	Multispectral cameras	70-mm or 5-in film
C.	Multispectral scanner	2.4 MHz per channel
D.	Radar images	film strip
E.	Absorption spectrometer	12,000 bits per sec
F.	Multichannel color sensor	12 kHz
G.	Radar altimeter	3.2 kilobits per sec
H.	Microwave scanner	500 kilobits per sec (maximum)
I.	Data collection system	256 bits per sec

5.7.5 Spacecraft Sizing for the Mission Example

There is a wide variation in the sizing of space research vehicles according to weight, but a gross estimate may be projected from the results of the analysis. The procedure to be followed is simply to use the crew-size projections obtained by the selection process and to enter the results in the sizing curves included in Subsection 5.3.3, Spacecraft Characteristics. A composite graph appears in Figure 5-62. Following through with the example, the final estimate of the technical crew size for the Earth Observation groups has been resolved to number between 6 and 8 men. By taking the number to be 7 technical crew members, the nomograph was entered at that value, and a total spacecraft crew size of 10 men was obtained. The crew number was then transferred to the second curve plotted from both actual and projected spacecraft weights. The initial weight estimate for 10 crew members is approximately 100,000 lb.

In the parallel study being conducted by MDAC on conceptual Space Station designs and the 12 configurations developed in the course of that study, a modular approach was offered. Each module was sized to a 33-ft diameter and 8-ft length. The number of modules used depends on the total experimentation requirements and crew size. The modules are configured for crew accommodation, operations activities, experiments, and docking and storage as required. For the 12 different configurations, the weight estimates ranged from 27,700 lb for the heaviest to 21,000 lb for the lightest. Taking the average to be 24,000 lb, the figure of 100,000 lb given above will resolve into a gross baseline estimate of four modules and a dimension estimate of approximately 33 ft in diameter by 32 ft in length.

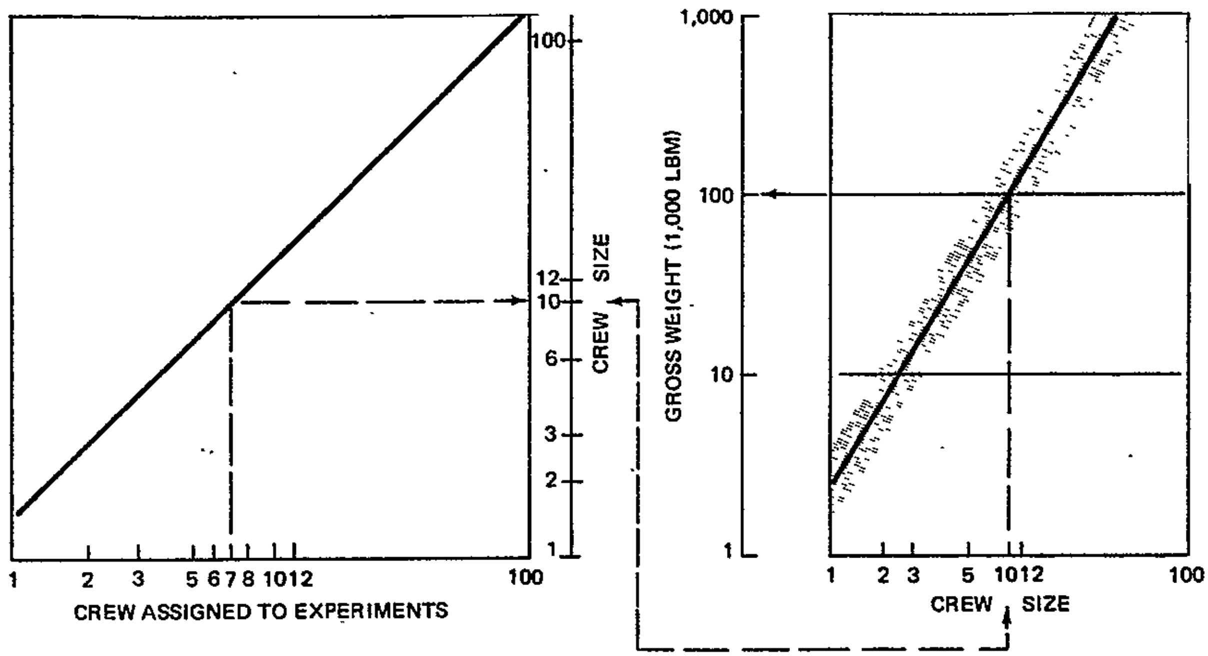


Figure 5-62. Nomograph: Crew Size to Spacecraft Weight

SECTION 6
SUPPORTING TECHNOLOGY DEVELOPMENT REQUIREMENTS

An important objective of this study was to assess the present capability to perform the experiments which have been defined. This assessment included an evaluation of current understanding, of component and systems capabilities, and of operational capabilities. Wherever it was determined that present capability was inadequate in any of these areas, a supporting technology development (STD) item was identified. This was done in order that technology deficiencies could be recognized early in the program, and implementation of the required development activities could be planned. This section of the report summarizes the STD requirements identified in Appendix E.

6.1 DERIVATION OF SUPPORTING TECHNOLOGY DEVELOPMENT REQUIREMENTS

As previously discussed, a requirement for supporting technology development (STD) exists whenever a future requirement cannot be satisfied with present technological capabilities. In the context of the Earth Orbital Experiment Program and Requirements Study (EOEPRS), an STD requirement exists when the level of technology specified by a research cluster description exceeds the known level of capability. Upgrading technological capabilities to meet predicted requirements may involve any of three basic types of STD activities:

1. Studies may be required to improve the level of theoretical knowledge in a discipline or to optimize a system design or an operational concept.
2. Experiments, either in space or not, may be required to better define the present capability, thus resolving whether or not a technological gap actually exists.
3. When the requirements and current capabilities are clearly defined, the development of components or systems may be undertaken directly.

These three major types of activities are the basis of the STD identification process in this study.

The definition of what constitutes a technological gap is intentionally made broad in order not to overlook subtle requirements and precursor events. For instance, a trade study is regarded as a valid STD item, even though experimental results might be obtained without such study, although at a degraded level or with a reduced probability of success. Hence, it is proper to identify such activities as required precursor events which insures that the experiment program will proceed from an assured basis of knowledge.

A major goal of the EOEPRS is to identify all the STD requirements necessary to support the research clusters described in Section 4. In addition to identification of these STD requirements, two supplementary goals have been adopted. First, the association of the identified STD items with the research clusters from which they were derived must be explicit. It is only with this information that the merits of funding a particular STD item can be evaluated. Similarly, the impact on STD requirements caused by the scheduling of a research cluster can be assessed. Second, the basic data necessary to organize an integrated program of study, experimentation, testing, and development must be obtained. With this information, the STD requirements can be carried further to assess their impact on existing programs and future resources and schedules.

In order to fulfill these study goals, a STD Requirement Description Form, was filled out initially by the discipline-oriented originator of the research cluster. It was then reviewed by the STD-oriented study team members. In many cases, conferences between these two sources led to identification and documentation of additional STD requirements.

The format used to document these STD items is shown in Figure 6-1. The STD item number is given in the upper right-hand corner of each page of the form. Item 1 gives a short title of the requirement, and item 2 a more complete description. The next two entries, items 3 and 4, provide traceability of the STD item to the relevant experiment requirement. This is done by listing the research cluster number (entry 3) and item number (entry 4) of the research cluster (or synopsis) description from which the STD item was derived.

The types of STD activities and STD objectives pertinent to the STD requirement being described are indicated in items 5 and 6. STD activities include studies,

STD ITEM
NO.

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

SUPPORTING TECHNOLOGY DEVELOPMENT
(STD) REQUIREMENT DESCRIPTION

1. STD TITLE.

2. BRIEF DESCRIPTION.

SOURCE FROM WHICH THIS STD REQUIREMENT IS DERIVED

3. RESEARCH CLUSTER(S). *From which STD item was derived*

4. ITEM NO(S). *In research cluster or synopsis from which STD item was derived.*

TYPE OF STD EFFORT

5. ACTIVITIES. *Studies, Experiments (in space, not in space), Developments.*

6. OBJECTIVES. *Theory, Component, System, Operation.*

DESCRIPTION OF TECHNOLOGICAL GAP

7. REQUIRED LEVEL OF THEORETICAL UNDERSTANDING, TECHNOLOGY, OR OPERATIONAL CAPABILITY. *Statement of the requirements as defined by items 3 and 4. This should state the problem, any unusual conditions, and basic operational concepts of the experiment(s).*

Figure 6-1. STD Requirement Description Format (Page 1 of 2).

STD ITEM
NO.

8. PRESENT LEVEL OF THEORETICAL UNDERSTANDING, TECHNOLOGY, OR OPERATIONAL CAPABILITY.

Statement of present state of the art relative to the requirements stated in item 7.

PROGRAMMATIC ASPECTS

9. CRITICALITY RATING.

List the rating — CRITICAL or IMPORTANT
Critical — some required experimental results will be unattainable without it.
Important — some required experimental results will be degraded or costly without it.

10. OTHER STD ITEMS WITH WHICH THIS STD REQUIREMENT COULD BE INTEGRATED.

Include operational capabilities which require upgrading.

11. SUGGESTED DEVELOPMENT APPROACH(ES).

If none are known — insert the word "none."

12. SPECIAL FACILITIES REQUIRED.

Laboratory, support, space, non-space.

13. KNOWN ONGOING ACTIVITIES WITH WHICH THIS STD REQUIREMENT COULD BE INTEGRATED.

14. ESTIMATE OF TIME SPAN TO ACHIEVE ADVANCEMENT.

15. ESTIMATE OF COST OF ACHIEVING ADVANCEMENT.

16. ESTIMATE OF CONFIDENCE IN ACHIEVING ADVANCEMENT.

High, medium or low.

Figure 6-1. STD Requirement Description Format (Page 2 of 2) experiments (either in space or not) to define the present state-of-the-art, and development. The objectives of these STD activities, i.e., the goals toward which these activities are directed, are also indicated. These objectives include an upgrading of existing theory; the study, development or testing of new components or systems; or the generation of a new or improved capability in manned operations.

The full description of the STD requirement is embodied in items 7 and 8 of the form. Item 7 shows the level of technological capability required by some facet of the research cluster. Item 8 includes the known state-of-the-art in the technology under consideration. Taken together, items 7 and 8 describe the technology that constitutes the requirement for STD. That is, an assessment of the gap between an experimental requirement and current state-of-the-art technology is the vital element in defining an STD item.

With a view toward the ultimate scheduling and funding of an organized STD program, information that goes beyond the STD identification alone is necessary. The remainder of the STD requirement description form is devoted to data of this character. In order to assess the relative value of STD items beyond that indicated by the value of the research clusters from which they were derived, an STD importance rating was devised. This is used to evaluate the importance of the STD item relative to the research goals of the research cluster to which it applies. An STD item is defined as critical if some required experimental results will be unattainable without it. If experimental results would be in some way degraded or made costly, but would still be obtainable, the STD item is termed important. These data appear in item 9.

The establishment of a development plan for each STD item is necessary before the required STD activities can begin. This involves consideration of study, experimental, or development programs already under way, the interactions of STD items among themselves, and necessary precursor-successor events. Information on these facets of the STD requirements is found in items 10, 11, and 13.

Another aspect of STD program planning is the impact of existing ground or space facilities that are required to accomplish the needed studies, experimentation and development. Data of this type indicate the load on existing facility operations and may show the requirements for new and expanded facility capabilities. Item 12 is used for recording this information.

Finally, time duration and cost estimates for each STD item are presented in items 14 and 15. In addition, an expression of confidence in the successful completion of the STD activity is entered in item 16. With these data, additional means of evaluating each STD item are available.

To facilitate the handling of the STD requirements identified in each study discpline, a numbering system was devised that retains much of the discipline and subdiscipline organization discussed in Section 4 of this report. This system is shown in Table 6-1. Complete STD descriptions, arranged in the disciplines and subdisciplines shown on Table 6-1 are presented in Appendix E.

6.2 SUPPORTING TECHNOLOGY

This section of the report presents discussions of the STD requirements for each of the study disciplines. Included in these discussions are summaries of the clusters and STD requirements; distribution profiles of the STD items according to activities, objectives, time durations, and costs; and conclusions relating to major trends in the STD requirements for each discipline.

6.2.1 Manned Space Flight Capability

For purposes of this study, Manned Space Flight Capability is divided into the three broad areas of Space Medicine, Engineering Experiments, and Operations Experiments, as shown in Figure 6-2. Space Medicine is further divided into four subdisciplines. Engineering Experiments (figure 6-3) consider the spacecraft systems with which man interacts or which are necessary to support him. Research in this area is concerned with experimental verification of advanced components and subsystems, and not with operational subsystems of the spacecraft. Operations Experiments involve evaluation of human performance, electromechanical performance, and procedures. An operation thus consists of a set of procedures performed by a man or team of men on some hardware element

Table 6-1

STD ORGANIZATION

Discipline and Subdiscipline	STD Number Key
Manned Space Flight Capability	
Space Medicine	
Biomedicine	BM-XX
Behavioral Research	BR-XX
Man-Machine Integration	MM-XX
Life Support and Protective Systems	LS-XX
Engineering Experiments	EE-XX
Operations Experiments	OE-XX
Space Biology	B-XX
Space Astronomy	A-XX
Space Physics	P-XX
Communications and Navigation	C-XX
Earth Observations	
Agriculture and Forestry	EF-XX
Earth Physics	
Geography and Cartography	EG-XX
Geology	
Hydrology	EH-XX
Meteorology	EM-XX
Oceanography	EO-XX
Instrumentation	EI-XX
Systems	ES-XX

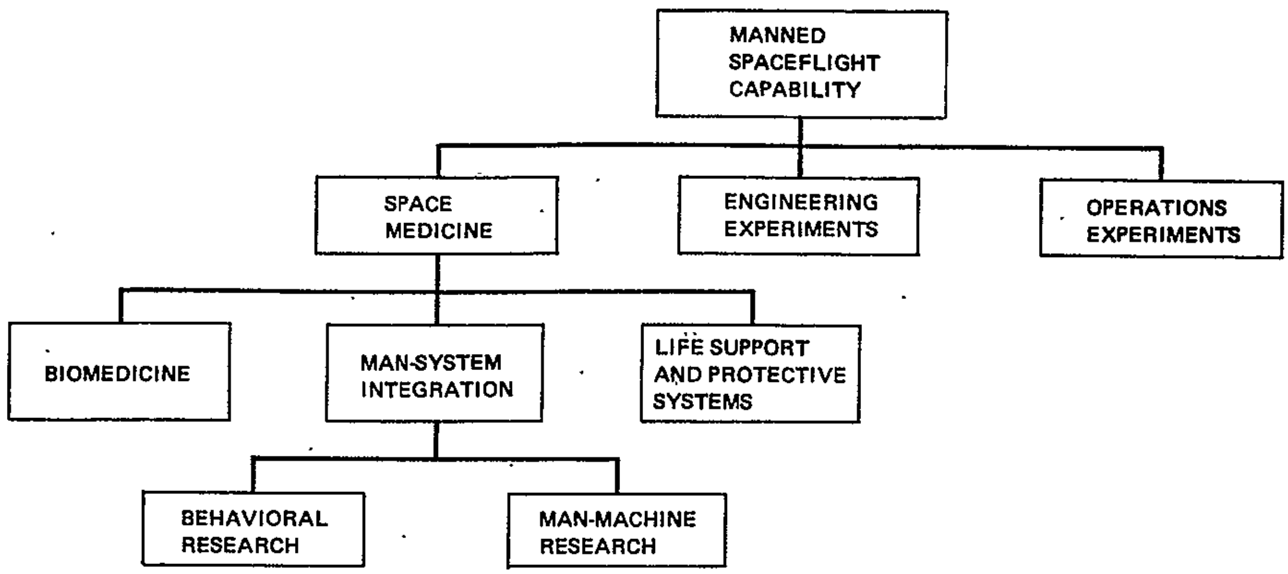
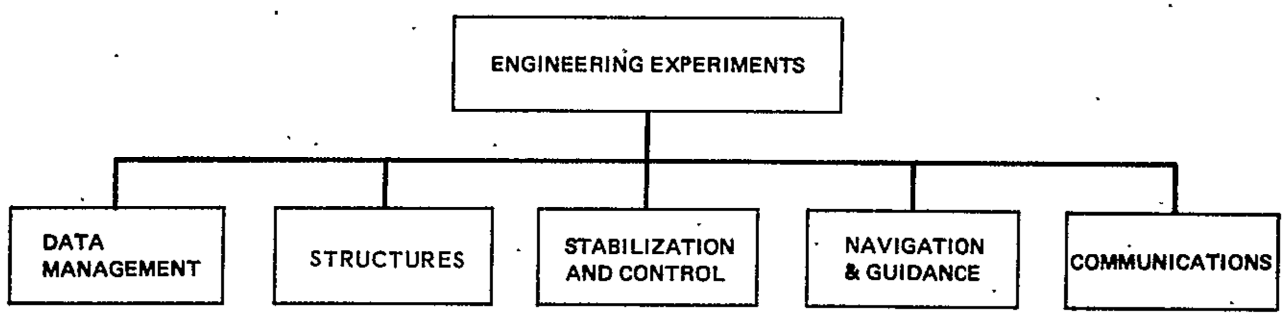


Figure 6-2. Major Subdivisions of Manned Spaceflight Capability.



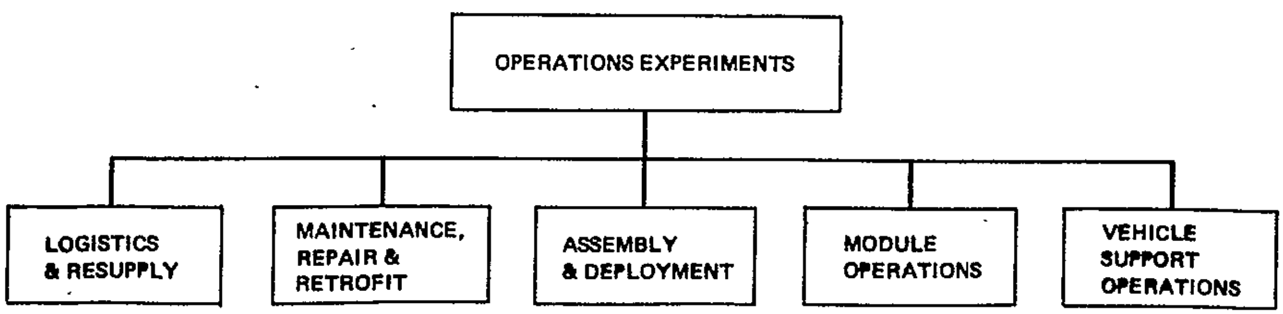


Figure 6-3. Major Subdisciplines of Engineering and Operations Experiments.

or group of hardware elements. Operations Experiments differ from Engineering Experiments in that the experimental questions are addressed to actual operations to be performed as part of a space mission. Numbers and titles for the research clusters analyzed for STD requirements are presented in Table 6-2. A more complete description is given in Appendix C.

6.2.1.1 Requirements

Analysis of the Research Clusters in Manned Space Flight Capability has led to the identification of 53 STD items. These are listed in Table 6-3, where key data is summarized for each. Details of each STD item are presented in Appendix E. A general overview discussion of these requirements is presented in the following paragraphs of this section.

Biomedicine

The key to experimentation in this area is accurate measurement. Although this capability exists in varying degrees in ground laboratories, much work is needed to develop this capability in space. Analysis of experiment requirements indicated that many of the required bio-instrumentation developments was covered by the Integrated Medical and Behavioral Laboratory Measurement System (IMBLMS) concept. Therefore, although this is vital to this program, these STD items were not included in Appendix E. It is quite important to note, however, that virtually every research cluster in this subdiscipline is heavily dependent on achievement of the objectives of the IMBLMS program.

Additional needs were also identified and are presented in Appendix E. These include development of improved

- Techniques for making neurological reflex measurements
- Techniques for making non-invasive central venous pressure measurements
- Techniques for accurate and simple measurements of gastro-intestinal motability
- Techniques and equipment for conducting hyperthermia tests
- Techniques and equipment for determining lean body mass
- Techniques and equipment for measuring transpulmonary pressure
- Facilities for providing animal life support
- Instruments and equipment to support tests utalizing animals

TABLE 6-2 (page 1 of 2)

MANNED SPACEFLIGHT CAPABILITY RESEARCH CLUSTERS

Cluster No.	Description
Biomedicine	
1-BM-4	Effects of weightlessness on circulatory function
1-BM-5	Radiation, toxicology, and medical problems
1-BM-6	Effects of weightlessness on stress response
1-BM-7	Effects of weightlessness on the nervous system
1-BM-8	Effects of weightlessness on gastrointestinal function
1-BM-10	Body fluid analysis
1-BM-12	Studies on instrument animals
1-BM-13	Effects of weightlessness on pulmonary function
1-BM-14	Effects of weightlessness on metabolism
1-BM-15	Centrifuge studies
Behavioral	
1-BR-1-1	Visual experiment
1-BR-1-2	Behavior effects of acoustic environment
1-BR-1-3	Psychomotor
1-BR-1-4	Cognitive capability
1-BR-1-5	Orientation
1-BR-2	Group dynamics and personal adjustment
1-BR-3	Complex task behavior
1-BR-4	Skill retention
1-BR-6	Performance measurement
Man-Machine Integration	
1-MM-1	Controls and displays
1-MM-2	Locomotion and restraint
1-MM-3	Habitability
1-MM-4	Work-rest-sleep cycles
1-MM-5	Performance aids

TABLE 6-2 (page 2 of 2)

Cluster No.	Description
Life Support and Protective Systems	
1-LS-1	Phase change and thermal processes
1-LS-2	Material transport processes
1-LS-3	Atmosphere supply processes
1-LS-4	Water management
1-LS-5	Water electrolysis
1-LS-6	Food management and processes
1-LS-7	Atmosphere purification methods
1-LS-8	Life support monitoring and control
1-LS-9	Waste management
1-LS-10	Heat transport equipment
1-LS-11	Crew equipment and protective systems
1-LS-12	Life support system maintenance and repair
Engineering Experiments	
1-EE-1	Data management
1-EE-2	Structures
1-EE-3-1	Drift measurement of gyroscopic attitude controls
1-EE-3-2	Disturbance torque measurements
1-EE-3-3	Biowaste electric propulsion
1-EE-4-1	Onboard laser ranging
1-EE-4-2	Interplanetary of translunar navigation by spectroscopic binary satellite
1-EE-4-3	Landmark tracker orbital navigation
1-EE-4-4	Navigation subsystem candidate evaluation
1-EE-5	Communications
Operations Experiments	
1-OE-1-1	Space logistics and resupply
1-OE-1-2	Emergency and rescue operations
1-OE-2	Maintenance, repair, and retrofit
1-OE-3	Assembly and deployment
1-OE-4	Module operations
1-OE-5	Vehicle support operations

TABLE 6-3 (page 1 of 2)

SUPPORTING TECHNOLOGY DEVELOPMENT DATA SUMMARY
MANNED SPACEFLIGHT CAPABILITY

STD NO.	STD TITLE	CRITICALITY	ACTIVITIES	OBJECTIVES	CONFIDENCE	TIME ESTIMATES (MONTHS)	COST ESTIMATES (THOUSAND DOLLARS)
	MANNED SPACEFLIGHT CAPABILITY – BIOMEDICINE						
BM-1	INFLIGHT BODY FLUID ANALYSIS	I	S	S,O	H	24	200
BM-2	NON-INVASIVE VENOUS PRESSURE MEASUREMENT	I	S	T,C	L	24	100
BM-3	ANIMAL TOXIOCOLOGICAL CHAMBER	C	D	S	H	24	1500
BM-4	MANNED ORBITAL ANIMAL RESEARCH FACILITY	C	D	S	H	36	5000
BM-5	RADIATION SOURCE	C	S	S	H	12	100
BM-6	SPACE THERMAL ENCLOSURE	C	NE	C	H	12	300
BM-7	SENSITIVE QUANTITATIVE EVALUATION OF REFLEX FUNCTIONS	I	NE	O	H	12	150
BM-8	ENDORADIOSONDE	I	NE	O	H	12	200
BM-9	ANIMAL SENSORS	C	S,D	C	H	24	1000
BM-10	ANIMAL MODULES	C	D	S	H	36	5000
BM-11	BODY VOLUMETER	C	D	T,S	M	12	750
BM-12	MEASUREMENT OF TRANSPULMANORY PRESSURE	I	D	C	H	24	100
	MANNED SPACEFLIGHT CAPABILITY – BEHAVIORAL RESEARCH						
BR-1	HEARING	I	NE	T,O	H	12	100
BR-2	AUDIO TONE SOURCE	I	D	C	H	12	100
BR-3	PSYCHOMOTOR TESTS IN SIMULATED ZERO-G	I	NE	O	H	12	300
BR-4	COGNITIVE MEASUREMENTS TEST MODULE	I	D	S	H	36	600
BR-5	AUTOMATED BEHAVIOR DATA FROM VIDEO AND AUDIO RECORDS	I	S,NE,D	O	H	36	750
BR-6	VERBAL BEHAVIOR ASSESSMENT PROGRAM	C	NE,D	T,O	H	24	750
BR-7	HAZARDOUS COMPLEX TASKS	I	S,NE	O	H	24	200
BR-8	TRAINING PROBLEMS AND EQUIPMENT	I	S,NE,D	C,O	H	24	1000
	MANNED SPACEFLIGHT CAPABILITY – MAN-MACHINE RESEARCH						
MM-1	DISPLAY/CONTROL COMPUTER CAPABILITY	C	D	S	H	36	1500
MM-2	DISPLAY/CONTROL EXPERIMENTAL APPARATUS	C	D	C	H	24	1000
MM-3	DARK ADAPTION EQUIPMENT AND TECHNIQUES	I	SE,NE	O	H	18	100
MM-4	PORTABLE METABOLIC ANALYZER	C	D	C	H	36	1500
MM-5	ONBODY ACCELEROMETER	C	D	S	H	36	400
MM-6	HABITABILITY EXPERIMENT SUPPORT PACKAGE	C	NE,D	S	H	36	1000
MM-7	EMERGENCY REACTION TIME FROM SLEEP	C	NE	O	H	24	200
MM-8	EQUIPMENT FOR SLEEP EXPERIMENTS	C	D	C	H	12	100
MM-9	PERFORMANCE AIDS	C	NE,D	S,O	H	60	5000

CRITICALITY:
C – CRITICAL
I – IMPORTANT

ACTIVITIES:
S – STUDY
SE – EXPERIMENT IN SPACE
NE – EXPERIMENT NOT IN SPACE
D – DEVELOPMENT

OBJECTIVES:
T – THEORY
C – COMPONENT
S – SYSTEM
O – OPERATIONS

CONFIDENCE:
H – HIGH
M – MEDIUM
L – LOW

TABLE 6-3 (page 2 of 2)

SUPPORTING TECHNOLOGY DEVELOPMENT DATA SUMMARY

MANNED SPACEFLIGHT CAPABILITY

STD NO.	STD TITLE	CRITICALITY	ACTIVITIES	OBJECTIVES	CONFIDENCE	TIME ESTIMATES (MONTHS)	COST ESTIMATES (THOUSAND DOLLARS)
	MANNED SPACEFLIGHT CAPABILITY – LIFE SUPPORT AND PROTECTIVE SYSTEMS						
LS-1	MULTIPURPOSE FLUID PHYSICS APPARATUS	C	S,D	S	H	24	1000
LS-2	ZERO-G CONDENSER	C	SE,NE,D	S,O	H	36	600
LS-3	CATALYST BED POISONS	I	D	C	H	12	250
LS-4	NEGATIVE PRESSURE DEVICE	I	NE,D	C	H	12	700
LS-5	ZERO-G PHASE SEPARATOR	C	SE, NE, D	C,S	H	24	400
LS-6	AUTOMATIC POTABILITY MEASURE	C	S,D	T,S	H	60	5000
LS-7	LOW FLOW METERING DEVICE	I	D	C	H	24	500
LS-8	SEPARATION OF EFFLUENT GASES FROM ELECTROLYTE	C	NE,D	S,O	H	30	750
LS-9	IDENTIFICATION OF CONTAMINANTS IN ELECTROLYSIS PRODUCTS	C	S,NE,D	S	H	24	500
LS-10	EVALUATION OF HYDROGENOMONAS EUTROPHA REACTION CHAMBER	C	D	S	H	12	600
LS-11	INTEGRATION OF HYDROGENOMONAS EUTROPHA SYSTEM COMPONENTS	C	D	S	H	24	200
LS-12	DEVELOPMENT OF CO_2 REMOVAL METHODS	C	D	T,S	H	24	800
LS-13	BOILING AND CONDENSING STEAM	C	NE,D	S,O	H	24	675
LS-14	WASTE MANAGEMENT SYSTEMS	C	D	S	H	24	800
LS-15	MICROBIAL DETECTION AND SUPPRESSION	C	S, NE, D	T,S	H	60 – 120	10000
LS-16	SYSTEMS INTEGRATION OF SENSORS	I	D	S	H	24	1500
LS-17	WASTE MANAGEMENT SYSTEM CONCEPTS	I	S	T,C,S	H	12	500
	MANNED SPACEFLIGHT CAPABILITY – ENGINEERING EXPERIMENTS						
EE-1	BIOWASTE ELECTRICAL PROPULSION	C	S,NE,D	S	H	36	2000
EE-2	BIOWASTE RESISTOJETS	C	S,NE,D	C	H	21	400
EE-3	BIOWASTE RESISTOJET EVA	C	S,NE	O	H	0 – 12	0 – 200
EE-4	LASER RANGING SYSTEM	C	S,D	S	H	36	3000
EE-5	LANDMARK TRACKER SYSTEM	C	S,D	S	H	18 – 24	3000
EE-6	LONG-RANGE OPTICAL COMMUNICATIONS	C	S,D	S	H	36	10000
	MANNED SPACEFLIGHT CAPABILITY – OPERATIONS EXPERIMENTS						
OE-1	ASSEMBLY TECHNIQUES STUDY	C	S,NE	O	H	18	500

It has been determined that these needs can be satisfied through utilization of ground-based studies and development. An examination of the "criticality" rating of the STD's presented in this subdiscipline (Table 6-3) indicates that while the improved bio-instrumentation and methods related to measurements on man are, in general, rated important, those related to animal housing, instrumentation, and testing are rated critical. This indicates that in accordance with the rating scheme discussed in Subsection 6.1, these latter experiment clusters can not be performed in their entirety without precursor development activities. The required experimentation on man, however, could be performed with alternate methods and equipment although the results would be degraded. Based on this criteria, therefore, it could be concluded that in this subdiscipline, the implementation of activities to support the animal experimentation should, in general, be given priority.

Behavioral Research

In evaluating the experiment requirements in this subdiscipline, it was determined that present capability does not fully meet the requirements, and that continuation of earlier work is needed. Most of the STD items in this subcategory fall into two general areas:

- Effects of long-term zero gravity on performance capability and on body systems deconditioning
- Techniques for measuring and evaluating personal and group attitudes and social adjustment

In addition, it will be necessary to develop an improved method of administering hearing tests and of conducting onboard training to maintain crew proficiency. These developments require study and ground laboratory and simulator testing.

The only STD which is critical is for continuation of ground-based research to improve the correlation between recorded audio data and crew mood and social adjustment (BR-6).

Man-Machine Research

The most significant need in this subdiscipline was found to be for the definition and development of the test methods and equipment which will be required to perform the experiments of Appendix C. Some examples of the type of activity required are:

- "Onboard" control and display test facilities and associated computer capabilities
- Techniques and equipment to improve operators dark adaptation capability
- Improved portable metabolic analyzer
- Body located devices for measuring local acceleration when working
- Techniques and equipment for measuring and evaluating the effects of habitability factors on crew performance
- Definition of tasks and development of equipment needed to evaluate man's emergency reaction capability after sleep
- Development of performance aids for evaluation in space

This latter item (STD No. MM-9) is the most significant in this subdiscipline in terms of development time. The estimated time to develop the required performance aids is five years. Although all of the remaining STD's in this subcategory are also rated critical, they generally all require shorter activity times (between 1.5 and 3 years). It can be concluded, therefore, that although all STD's must be implemented to meet experiment requirements, development of the required flight qualified performance aids should be given priority.

Life Support and Protective Systems

The earth orbital experiments in this subdiscipline involve the inflight evaluation and comparison of a wide variety of advanced subsystems. Prior to conducting these tests in space, it will be necessary to continue development of these systems to a flight-ready status. The STD items in this subdiscipline therefore are concerned quite extensively with systems and component development. The subsystems of concern include:

- Fluid transport and phase separation
- Atmospheric supply and purification
- Water supply and purification

- Food management
- Waste management
- Microbial detection and suppression
- Hazard monitoring and crew protection

An examination of the specific STD descriptions in Appendix E indicates that much of this development requires a manned ground simulation similar to the 90-Day Test. In this simulation, however, advanced life support subsystems would be used.

Two STD items in this subcategory need to be singled out for special attention. Both the development of an advanced automatic potability measurement system (LS-6), and the development of an advanced system for microbial detection and suppression(LS-15) are quite time consuming in comparison with other STD items. They are also both rated critical. Consequently, these are regarded as high priority items in this subcategory.

Engineering and Operations Experiments

In the subdiscipline of Engineering Experiment, as with several others discussed previously, the STD items are generally concerned with the definition and development of the test methods and equipment needed to perform the experiments of Appendix C. The study has determined that integrated systems which meet the experiment requirements have not been developed and evaluated to the degree required for flight readiness.

The six STD items in the Engineering Experiments subdiscipline are all critical and are related to four advanced systems concepts.

- Biowaste electric propulsion
- Laser ranging
- Landmark tracking
- Long-range laser communications

In the subdiscipline of Operations Experiments, the only STD identified was for the definition and precursor ground simulation of the EVA techniques and equipment required to assemble a large antenna boom in space to support Research Cluster 1-OE-3.

Commonality of STD Items

This study also included an investigation into the commonality of STD items to more than one research cluster. The results are presented in Table 6-4. It can be seen that in the subdisciplines of Life Support and Protective Systems, Engineering Experiments, and Operations Experiments, failure to implement a specific STD activity may impact more than one research cluster in that subdiscipline. This commonality should also be considered when planning STD implementation programs.

6.2.1.2 Data Summary

This section of the document presents summary STD data and remarks on (a) type of activities, (b) objectives, (c) development times, and (d) costs. The basic data are taken from the individual STD Requirements Description forms in Appendix E.

(a) Activities. - Types of STD activities in the Manned Space Flight Capability discipline are presented in Table 6-5.

TABLE 6-5

ACTIVITY CATEGORIES

Activities / Subdiscipline	Study	Experiments		Development
		In Space	Not in Space	
Biomedicine	4	0	3	6
Behavioral	3	0	6	5
Man-machine	0	1	4	7
Life support	5	2	7	16
Engineering and Operations	7	0	4	5
Total	19	3	24	39

TABLE 6-4 (page 1 of 2)

MANNED SPACE FLIGHT CAPABILITY COMMONALITY MATRIX

STD NUMBER	STD TITLE	RESEARCH CLUSTER NUMBER																															
		1-BM-4	1-BM-5	1-BM-6	1-BM-7	1-BM-8	1-BM-10	1-BM-12	1-BM-13	1-BM-14	1-BR-1-2	1-BR-1-3	1-BR-1-4	1-BR-2	1-BR-3	1-BR-4	1-MM-1	1-MM-2	1-MM-3	1-MM-4	1-MM-5	1-LS-1	1-LS-2	1-LS-3	1-LS-4	1-LS-5	1-LS-6	1-LS-7	1-LS-8	1-LS-9	1-LS-10	1-LS-11	1-LS-12
	BIOMEDICINE																																
BM-1	INFLIGHT BODY FLUID ANALYSIS						I																										
BM-2	NONINVASIVE CENTRAL VENOUS PRESSURE MEASUREMENT TECHNIQUE	I																															
BM-3	ANIMAL TOXICOLOGICAL CHAMBER		C																														
BM-4	MANNED ORBITAL ANIMAL RESEARCH FACILITY		C																														
BM-5	RADIATION SOURCE		C																														
BM-6	SPACE THERMAL ENCLOSURE			C																													
BM-7	SENSITIVE QUANTITATIVE EVALUATION OF REFLEX FUNCTIONS				I																												
BM-8	ENDORADIOSONDE					I																											
BM-9	ANIMAL SENSORS							C																									
BM-10	ANIMAL MODULES							C																									
BM-11	BODY VOLUMETER									C																							
BM-12	MEASUREMENT OF TRANSPULMONARY PRESSURE								I																								
	BEHAVIORAL																																
BR-1	HEARING										I																						
BR-2	AUDIO TONE SOURCE										I																						
BR-3	PSYCHOMOTOR TESTS IN SIMULATED ZERO-G											I																					
BR-4	COGNITIVE MEASUREMENTS TEST MODULE												I																				
BR-5	AUTOMATED BEHAVIOR DATA FROM VIDEO AND AUDIO RECORDS													I																			
BR-6	VERBAL BEHAVIOR ASSESSMENT PROGRAMS													C																			
BR-7	HAZARDOUS COMPLEX TASKS														I																		
BR-8	TRAINING PROBLEMS AND EQUIPMENT															I																	
	MAN-MACHINE RESEARCH																																
MM-1	DISPLAYS/CONTROLS COMPUTER CAPABILITIES																C																
MM-2	DISPLAYS/CONTROLS EXPERIMENTAL APPARATUS																C																
MM-3	DARK ADAPTION EQUIPMENT AND TECHNIQUES																I																
MM-4	PORTABLE METABOLIC ANALYZER																	C															
MM-5	ON-BODY ACCELEROMETER																	C															
MM-6	HABITABILITY EXPERIMENT PACKAGE																		C														
MM-7	EMERGENCY REACTION TIME FROM SLEEP																			C													
MM-8	EQUIPMENT FOR SLEEP EXPERIMENTS																			C													
MM-9	PERFORMANCE AIDS																				C												
	LIFE-SUPPORT																																
LS-1	MULTIPURPOSE FLUID PHYSICS APPARATUS																					C	C	I	C	C		I		I	I		
LS-2	ZERO-G CONDENSER																					I		C	I						I		
LS-3	CATALYST BED POISONS																							I				I	I			I	I
LS-4	NEGATIVE PRESSURE DEVICE																						I	I	I								
LS-5	ZERO-G PHASE SEPARATOR																								C	C	I			I			
LS-6	AUTOMATIC POTABILITY MEASUREMENT																								C				I			I	I
LS-7	LOW FLOW METERING DEVICE																								I					I			
LS-8	SEPARATION OF EFFLUENT GASES FROM ELECTROLYTE																									C		C					I
LS-9	IDENTIFICATION OF CONTAMINANT IN ELECTROLYSIS PRODUCTS																									C		I	I			I	I
LS-10	EVALUATION OF HYDROGENOMONAS EUTROPHIA REACTION CHAMBER																										C	I				I	
LS-11	INTEGRATION OF HYDROGENOMONAS EUTROPHIA SYSTEM COMPONENTS																										C	I		I			
LS-12	DEVELOPMENT OF CO_2 REMOVAL METHODS																							C				C				I	
LS-13	BOILING AND CONDENSING STEAM																					C		I				I					
LS-14	DEVELOPMENT OF WASTE MANAGEMENT SYSTEMS																										I			C			
LS-16	MICROBIAL DETECTION AND SUPPRESSION																							I				I	I			C	I
LS-16	SYSTEMS INTEGRATION OF SENSORS																							I				I	I			I	I
LS-17	WASTE MANAGEMENT SYSTEM CONCEPTS																													I			

C - CRITICAL, I - IMPORTANT

TABLE 6-4 (page 2 of 2)

MANNED SPACE FLIGHT CAPABILITY COMMONALITY MATRIX

STD NUMBER	STD TITLE	ENGINEERING EXPERIMENT RESEARCH CLUSTERS									OPERATIONS EXPERIMENTS RESEARCH CLUSTERS				
		1-EE-2	1-EE-3-1	1-EE-3-2	1-EE-3-3	1-EE-4-1	1-EE-4-2	1-EE-4-3	1-EE-4-4	1-EE-5	1-OE-1-1	1-OE-1-2	1-OE-3	1-OE-4	1-OE-5
	ENGINEERING EXPERIMENTS														
EE-1	BIOWASTE ELECTRICAL PROPULSION				C										
EE-2	BIOWASTE RESISTOJETS				C										
EE-3	BIOWASTE RESISTOJET EVA				C										
EE-4	LASER RANGING SYSTEM					C	I		I						
EE-5	LANDMARK TRACKER SYSTEM							C	I						
EE-6	LONG-RANGE OPTICAL COMMUNICATIONS						I			C					
	OPERATIONS EXPERIMENTS														
OE-1	ASSEMBLY TECHNIQUES STUDY										I	I	C	I	

C - CRITICAL
I - IMPORTANT

These data indicate that the predominant needs in this discipline are for development and ground experimentation type activity. Few of the STD's require precursor flight experiments.

(b) Objectives. - The STD requirements are presented in terms of objectives in the following Table 6-6.

TABLE 6-6

OBJECTIVE CATEGORIES

Subdiscipline \ Objectives	Theory	Component	System	Operation
Biomedicine	2	4	6	3
Behavioral	2	2	1	6
Man-machine	0	3	4	3
Life support	4	5	14	3
Engineering and Operations	0	1	4	2
Total	8	15	29	17

The totals indicate that for this discipline, and for most of the subdisciplines, the objective of a majority of the STD items is advancement in system technology. The least number are directed toward upgrading existing theory.

(c) Development Times. - Generally speaking, virtually all of the STD activity times in this discipline are between 1.5 and 3 years. (see Table 6-3.) Three notable exceptions are:

- STD No. MM-9 Performance Aids - 5 years
- STD No. LS-6 Automatic Potability Measure - 5 years
- STD No. LS-15 Microbial Detection & Suppression - 5-10 years

As noted in Subsection 6.2.1.1, these relatively long development times, coupled with the fact that each of the STD's is rated critical, are felt to impart a degree of priority to these items.

(d) Costs. - Cost estimates are summarized in the following Table 6-7:

TABLE 6-7

COST ESTIMATES

Subdiscipline	Cost (thousands)
Biomedicine	$14,400
Behavioral	3,800
Man-machine	10,800
Life Support	24,775
Engineering and Operations	19,100
Total	$72,875

An examination of costs on an item by item basis (Table 6-3) reveals that the majority of individual STD's generally cost between about $100,000 and $800,000. As might be expected, the major cost STD's items are those associated with development of advanced hardware.

6.2.1.3 Conclusions

In the process of defining and evaluating the supporting technology development requirements in the category of Manned Space Flight Capability, several general observations became apparent. These will be reviewed in the following paragraphs:

Biomedicine

It was established that advanced bioinstrumentation development is vital to this subcategory. This requirement was evident for virtually every research cluster in this subdiscipline. It was also found that the IMBLMS concept will, when brought to a successful hardware stage, meet most of the instrument requirements of this subdiscipline. It is quite important, therefore, that this program continue to completion. An additional conclusion was that the state-of-the-art hardware and instrumentation to support the required animal experiments is not presently adequate and that implementation of development of these systems is required.

Behavioral Research

The primary requirements in this subdiscipline was found to be for the continuation of previous ground-based research related to zero gravity deconditioning and on unobtrusive determination of crew attitude and social adjustment. Of particular importance is the need to continue development of techniques for establishing crew attitudes through analysis of audio records. It is also desirable to establish several new or improved test and data evaluation techniques.

Man-Machine Research

The need for the development of a number of different systems required to perform those experiments in this subdiscipline was identified. In general, it is felt that these developments should be straightforward extensions of the current technology, and that only one of these (advanced performance aids for inflight evaluation) is very demanding in terms of cost or time.

Life Support

Experimentation in this subcategory involves the inflight evaluation of a variety of advanced systems and/or components. It was concluded that the majority of these are not yet at a flight ready status. The major technology need was found to be for continuation of development of advanced concepts in almost all areas of life support. This ground-based development effort generally culminates in an integrated system test using a manned simulator. Of particular importance are an automatic water potability measuring system and an advanced microbial detection and suppression system.

Engineering and Operations Experiments

An evaluation of the STD items in the Engineering Experiments subdiscipline indicates the same general conclusion as for the Life Support and Protective Systems subdiscipline. Generally, the advanced systems which the research will evaluate in space operations, have not been developed to a flight ready status. It has been concluded that ground development activities for biowaste electric propulsion, laser ranging, land-mark tracking, and long-range laser communications will be required before the flight evaluations can be performed.

In the area of Operations Experiments, it has been concluded that, with one exception, the experiments can be performed with present technology. An exception is the EVA assembly of a large antenna, which will require precursor studies and simulations.

6.2.2 Space Biology

The discipline of the Space Biology was organized on the basis of specimen commonality rather than process commonality. Consequently, four major groupings were established for the four major specimen categories - vertebrates, plant, protist, and invertebrates. In addition, limitations of crew size, available time, and specialized skills in early spaceflight leads to experiment designs which, at first, require minimal crew involvement; next, moderate involvement; and, later, extensive crew involvement. As a result of these considerations, the following three phases were established for each specimen-oriented cluster:

> Phase 1 of vertebrate, plant, protist, and invertebrate biology is designed to require a minimal effort by the astronauts. The biological specimens must be maintained, and meaningful observations of their activities will be made by the astronauts. Tissue samples will be preserved.
>
> Phase 2 will call for use of standard analytical equipment that requires some specimen preparation. For example, the microscope, the spectrophotometer, or the gas chromatograph will be utilized for sample analysis. The participation of a trained astronaut will be required.
>
> Phase 3 is much more sophisticated and requires extensive preparation of samples before the critical issues can be evaluated. Trained biologists will be required to perform the experiments in space. Liquid scintillation-counting techniques and mass spectrometry will be used to evaluate the selected parametric values with precision.

Table 6-8 lists the Space Biology Research clusters which were analyzed for STD requirements. Note that the first part of the research cluster numbers are keyed to the specimen category (e.g. 2-VB vertebrates, 2-PL plants, 2-P/T protists and tissues, and 2-IN invertebrates); whereas, the last number defines the research cluster phasing. This will facilitate the association of the research cluster disciplines with the subsequent analysis of supporting technology development items.

Table 6-8

SPACE BIOLOGY RESEARCH CLUSTERS

Number	Research Cluster Title
2-VB-1	Preliminary Investigation of Biological Processes, Using Primates and Small Vertebrates
2-VB-2	Intermediate Investigations of Biological Processes, Using Primates and Small Vertebrates
2-VB-3	Advanced Investigations of Biological Processes, Using Primates and Small Vertebrates
2-PL-1	Preliminary Investigations of Biological Processes, Using Plants
2-PL-2	Intermediate Investigations of Biological Processes, Using Plants
2-PL-3	Advanced Investigations of Biological Processes, Using Plants
2-P/T-1	Preliminary Investigations of Biological Processes, Using Unicellular Specimens (protists and tissue cultures)
2-P/T-2	Intermediate Investigations of Biological Processes, Using Unicellular Specimens (protists and tissue cultures)
2-P/T-3	Advanced Investigations of Biological Processes, Using Unicellular Specimens (protists and tissue cultures)
2-IN-1	Preliminary Investigations of Biological Processes, Using Invertebrates
2-IN-2	Intermediate Investigations of Biological Processes, Using Invertebrates
2-IN-3	Advanced Investigations of Biological Processes, Using Invertebrates

6.2.2.1. Requirements

Analysis of the 12 research clusters in Space Biology has led to the identification of 21 STD requirement items for which there is no existing applicable equipment or technique. These items are listed in Table 6-9, where the "B" prefix denotes Space Biology. Each item in the table corresponds to an STD Requirement Description presented in Appendix E. The STD items presented in Table 6-9 include study of techniques such as surgical procedures and liquid handling in zero g; equipment whose current terrestrial laboratory counterpart involved significant gravity-dependent processes; items of equipment which currently lack the accuracy and the precision demanded by the experiment cluster; and a study to analyze and integrate currently acceptable equipment into a space laboratory. The full documentation of space biology STD items can be found in Appendix E.

6.2.2.2. Data Summary

The STD items that were identified in the discipline of space biology (Table 6-9) are compared in a commonality matrix that lists STD items versus the space biology research clusters. For each STD item, an importance rating is shown relative to each research cluster by entering either a "C" (for critical) or an "I" (for important) at the appropriate intersection of the matrix. Table 6-10 presents the commonality matrix for space biology. It must be emphasized that the importance rating of an STD item is determined from this matrix and not from the rating given on the research cluster description form which relates only to the research cluster being considered at the time the STD requirement is identified. That is, it is quite possible to derive an STD item rated important with respect to the originally considered research cluster and then later find that the same STD item is critical with respect to another cluster. Commonality outside the space biology study area is given in Table 6-25 in the program synthesis discussion.

Examination of the matrix shows that six STD items (B-1, B-4, B-13, B-20, and B-21) are required in all of the space biology experiments. The vertebrate research clusters require 18 of the 21 STD items, of which 5 are unique to vertebrate biology. Also, it is observed that 3 STD items are unique to the

Table 6-9

SPACE BIOLOGY S1D ITEMS

STD Number	STD Title
B-1	Amino Acid Analyzer
B-2	$-180^{\circ}C$ Tissue Freezer
B-3	Zero G Animal Cages
B-4	Animal Biocentrifuge
B-5	Surgical Procedures
B-6	Zero G Autoclave
B-7	Zero G Incubator
B-8	Tissue Processor
B-9	Activity Platform
B-10	Visual Cliff
B-11	Animal Maze
B-12	Bunsen Burner Substitute
B-13	Liquid Handling
B-14	Automated Microbial Identification
B-15	Zero G Homogenizer
B-16	Dialysis Equipment
B-17	Blood Cell Counter
B-18	Fluid Electrolyte Analyzer
B-19	Advance Plethysmograph
B-20	Small Particle Mass Measurement
B-21	Equipment Analysis and Integration

TABLE 6-10. SPACE BIOLOGY COMMONALITY MATRIX

STD NUMBER	STD TITLE	SPACE BIOLOGY RESEARCH CLUSTERS			
		VERTEBRATE	INVERTEBRATE	PLANT	PROTIST
B-1	AMINO ACID ANALYZER	C	C	C	C
B-2	-180°C TISSUE FREEZER	C	C	C	
B-3	ZERO-G ANIMAL CAGES	C	I		
B-4	ANIMAL BIOCENTRIFUGE	C	C	C	C
B-5	SURGICAL PROCEDURES	C			
B-6	ZERO-G AUTOCLAVE	I			C
B-7	ZERO-G INCUBATOR				C
B-8	TISSUE PROCESSOR	I	I	I	I
B-9	ACTIVITY PLATFORM	I			
B-10	VISUAL CLIFF	I			
B-11	ANIMAL MAZE	I			
B-12	BUNSEN BURNER SUBSTITUTE				I
B-13	LIQUID HANDLING	C	C	C	C
B-14	AUTOMATED MICROBIAL IDENTIFICATION				I
B-15	ZERO-G HOMOGENIZER	C	C	C	
B-16	DIALYSIS EQUIPMENT	C	C	C	
B-17	BLOOD CELL COUNTER	I			
B-18	FLUID ELECTROLYTE ANALYZER	C	C	C	
B-19	ADVANCED PLETHYSMOGRAPH	I			
B-20	SMALL PARTICLE MASS MEASUREMENT	C	C	C	C
B-21	EQUIPMENT ANALYSIS AND INTEGRATION	I	I	I	I

C -- CRITICAL

I -- IMPORTANT

protists research clusters and no STD items are unique to the invertebrate and plant research clusters. In addition, 6 STD items (B-2, B-3, B-6, B-15, B-16, and B-18) have multiple requirements within the space biology experiments. These data are shown in Figures 6-4 and 6-5. It is interesting to note that the 31 activities identified consists of 9 studies; 6 experiments, and 16 development requirements. Similarly, the 28 objectives identified consists of 7 component, 9 systems, and 12 operational categories, with no theoretical objectives identified.

Figure 6-6 shows the time required to perform the STD activities. The number of months estimated for individual STD items have been listed and are shown in the bar chart. Where a maximum and minimum time is given on the STD description form, the average has been computed and is plotted here. Most STD efforts can be accomplished within 24 months. The longest durations are required to develop the Automated Microbial Identification System (STD No. B-14) and the Animal Biocentrifuge (STD No. B-4).

The cost of performing each STD item has been estimated by practicing biologists. Development of the components and systems required to perform zero gravity biology experiments is not as well understood as experiments in the earth environment. The estimated costs were usually stated as falling between upper and lower limits that have been averaged for use in a chart. The cost estimates were therefore averaged and classified as shown in Figure 6-7. It may be observed that 70 percent of the STD items have been estimated to cost $500 thousand or less. The STD items that have received the highest estimates are the Amino Acid Analyzer (STD No. B-1); the Animal Biocentrifuge (STD No. B-4); and STD No. B-21, Equipment Analysis and Integration.

6.2.2.3. Conclusions

The supporting technology development for the Space Biology experiments included several types of requirements. Only two items, the advanced plethsmograph and the automated microbial identification system, are not presently available for ground-based research and require an advancement in the state-of-the-art rather than a redesign for zero g. Seven of the STD items identified were items of

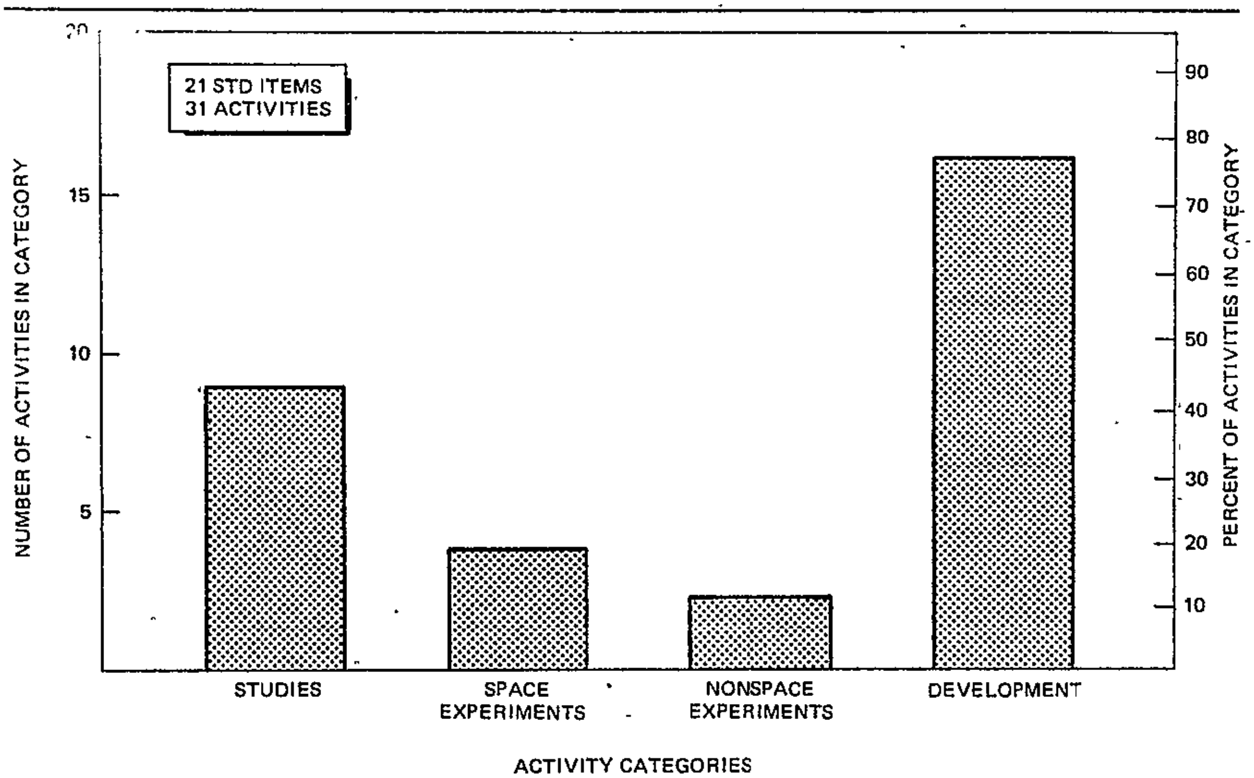


Figure 6-4. Space Biology - STD Activities Distribution

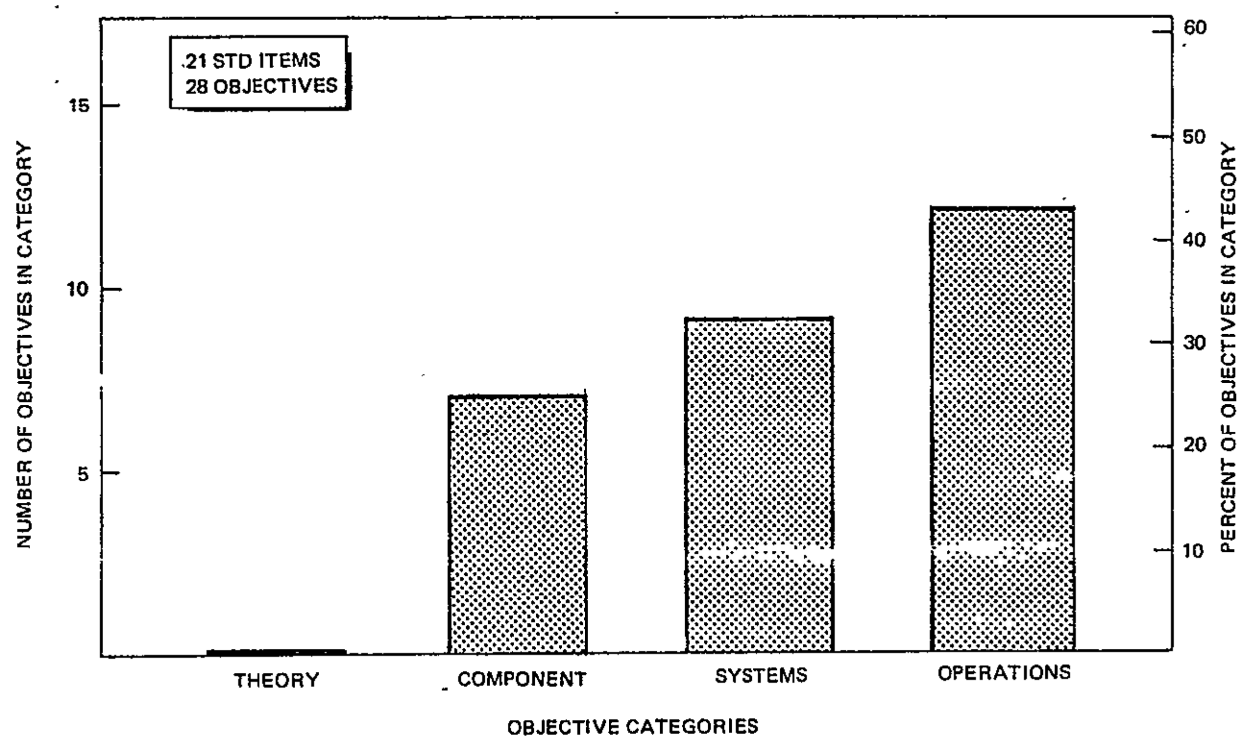


Figure 6-5. Space Biology-STD Objectives Distribution.

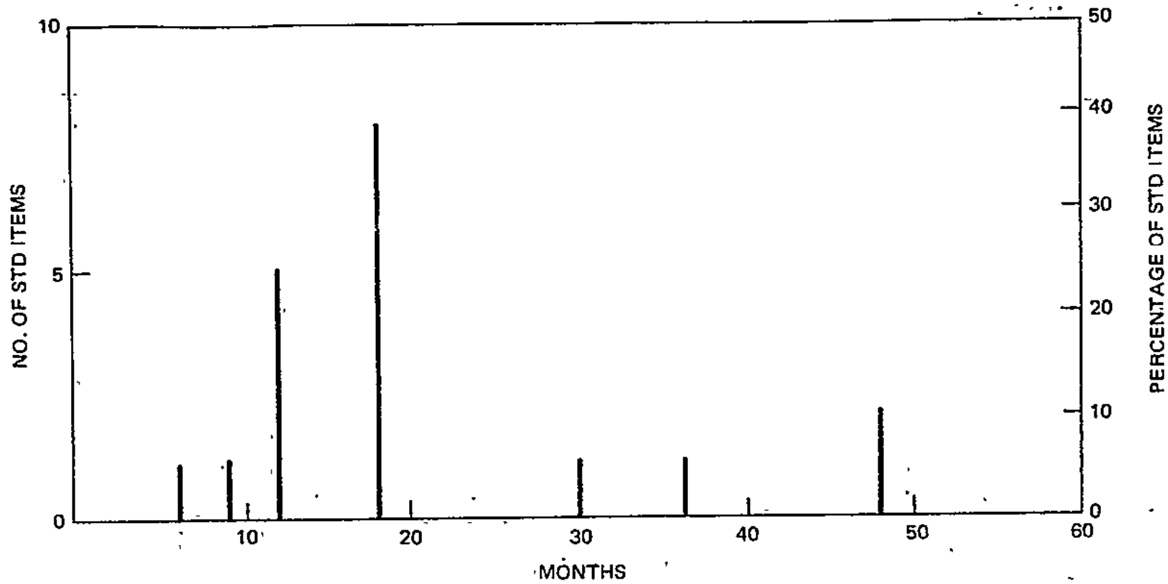


Figure 6-6. STD Time Estimates for Space Biology (21 STD Items).

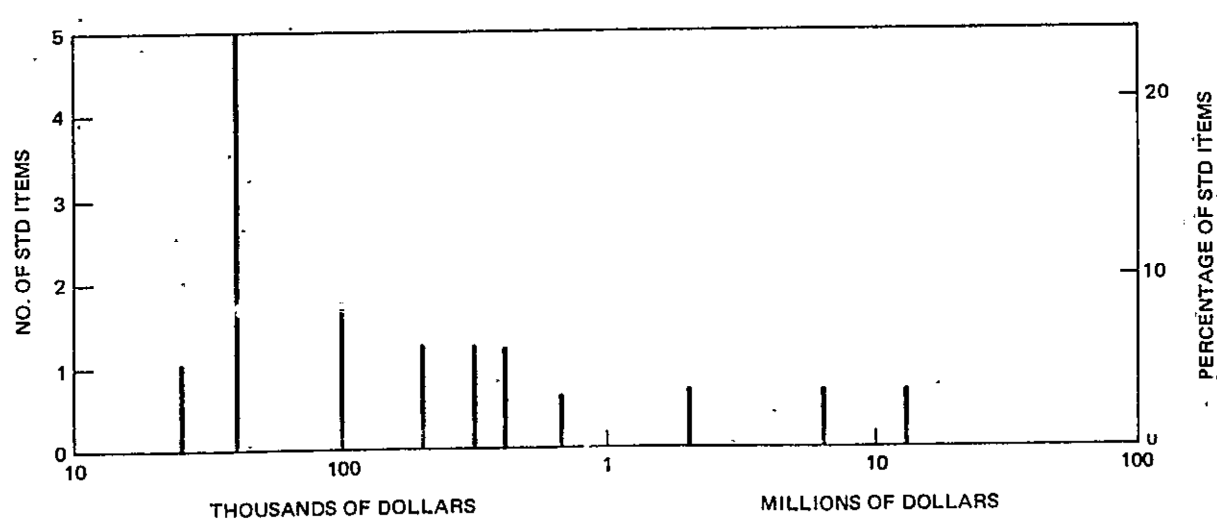


Figure 6-7. STD Cost Estimates for Space Biology (21 STD Items).

equipment, presently available and acceptable, but whose function involved gravity dependent fluid flow characteristics and would, consequently, require a redesign for zero g use. Similarly, five of the items involved gravity dependent mass effects and required modification on these basis. The remaining items were distributed among studies to define procedures, techniques, and general requirements for laboratory equipment and items which, in their present form, would impact the orbital research facility unfavorably.

6.2.3. Space Astronomy

Ongoing orbital astronomy programs of the 1970's continue to emphasize stellar and galactic optical observations plus solar optical, ultraviolet, and x-ray work. Also included are low-frequency radio measurements of emissions by the solar corona and interplanetary, interstellar, and intergalactic plasmas, plus the beginning of orbital x- and gamma-ray observations of galactic and extragalactic sources.

The major emphasis in man-supported orbital astronomy would be on optical observations of extragalactic objectives, solar system observations with high angular resolution (which require large optical telescopes), and low-frequency radio observations as in the ongoing programs. Also included would be high-angular-resolution measurements of x- and gamma-ray sources. These instruments would require EVA assembly because of their size and intricacy.

Although there are only seven research clusters in astronomy (see Table 6-11), they are grouped in such a manner as to cover the complete spectrum and activities relating to space astronomy. These research clusters were derived from the critical issues identified in Section 2.

6.2.3.1. Requirements

From the seven space astronomy research clusters, thirteen STD items were identified (see Table 6-12). [illegible] the STD items includes a broad spectrum of technological gaps, particularly STD items A-1 and A-8. These two cover 14 major issues which, in turn, include additional subsystem and technology STD items. It is estimated that over 150 STD items would have been written for these two major items, but their interrelations are so extensive that it was felt they should be grouped and handled as one package.

6.2.3.2. Data Summary

The applicability of the STD items to the research clusters is shown in the commonality matrix, Table 6-13. Each item is applicable to four or more of the research clusters. For each entry, either a C (for critical) or an I (for important) is used.

Each STD item identifies one or more of four activities: study, space experiment nonspace experiment, and development. For the 13 astronomy items, 35 activities have been identified. The distribution of these activities is shown in Figure 6-8. Each of the thirteen STD items calls for a study; that is about 37 percent of the activities identified. The other activities consist of experiments (40 percent), and development (23 percent). One or more objectives were established for each STD item; theory, components systems or operations.

Of the 13 astronomy items, 32 objectives were defined. There are presently broken down as follows: about 1/3 for systems, slightly over 1/4 for components, and operations each, and slightly less than 10 percent for theory (see Fig. 6-9).

The frequencies of time estimates are given in Figure 6-10. It is estimated that about 30 percent of these items can be accomplished in a year or less, and about 85 percent in three years or less. Approximately 15 percent (2 items) are so extensive that they will require an estimated ten years to accomplish.

The frequencies of cost estimates for achieving the STD objectives are shown in Figure 6-11. Generally, the estimates for each item assumed independent costs; i.e., no cost sharing. These estimates range from \$100,000 to \$750,000. However, the wide cost spreads (\$50,000,000 to \$500,000,000) of the two items with the highest cost (and time) estimates are due to the recognition of potential commonalities.

Table 6-11

SPACE ASTRONOMY RESEARCH CLUSTERS

No.	Research Cluster Title	Research Objective
3-OW	Optical Structure of Small Extended Sources	Optical Measurements of Stellar Objects
3-XR	Precise Location, Size, and Structure of Known Discrete X-Ray Sources and Existence of Additional Unknown Sources	Location of X-Ray Sources
3-LF	Location and Properties of Discrete Low-Frequency Radio Sources, and Structure and Properties of Diffuse Sources	Location of Radio Sources
3-OB	High-Resolution Planetary Optical Imagery (in process)	Optical Measurements - Planetary
3-OS	Optical (Faint Threshold) Surveys	Optical Search for Faint Objects
3-SO	Optical Studies of the Solar Photosphere and Chromosphere	To Define the Fine Physical Structure of the Solar Photosphere and Chromosphere
3-OP	High Precision Stellar Photometry	To Provide Microfluctuations in the Observed Flux Density of Stellar Objects

6.2.3.3. Conclusions

Unfortunately, operational details and support system concepts are lacking to the extent that further studies are needed in logistics, maintenance, use of photographic film, and erection of large structures in space (EVA). STD items cover these areas in studies for further concepts and space state-of-the-art (EVA, thermal control , logistic resupply, and maintenance operations).

One of the least-addressed subjects in space astronomy is that of celestial coordinate systems and the related operation of target acquisition. These items are critical and must be worked out early in the program since many required experiments cannot be accomplished without these advancements.

Photographic film plays a very important part in space astronomy, with about 60 percent of the requirements in the ultraviolet and x-ray region requiring

Table 6-12

SPACE ASTRONOMY STD ITEMS

STD No.	STD Title
A-1	High-Resolution Optical Systems
A-2	Advanced Electronic Image Intensifiers
A-3	Telescope Operation in Space
A-4	Orbit-to-Orbit Shuttle Requirements
A-5	Assembly and Alignment of High-Resolution Telescope in Space
A-6	Developments for Use of High-Resolution Telescope
A-7	Development of Use of Photographic Film for Space Astronomy
A-8	High-Resolution Optical Telescopes
A-9	Electronic Image Intensifiers
A-10	Acquisition of Celestial Targets
A-11	High-Precision Stellar Photometry
A-12	Cooling of Solar Astronomy Telescopes
A-13	Acquisition and Tracking of Solar Targets

Schumann-type film. This must be processed wet in zero gravity, a problem not yet addressed to any great extent.

Finally, the erection and alignment of telescopes (3-meter) in high orbits (possibly synchronous) will require some generally exotic concepts, even for feasibility assessment. The upgrading of present EVA capability will certainly be necessary, and much more will need to be known before concepts can even be proposed. The alignment of a 3-meter, diffraction-limited telescope in an air-conditioned laboratory is difficult enough. How this can be accomplished in space is a matter for conjecture and is essentially unaddressed at this time. Studies are necessarily early, as they affect not only the whole mission using this instrument, but also the design of the instrument itself.

TABLE 6-13. SPACE ASTRONOMY COMMONALITY MATRIX

STD NUMBER	STD TITLE	ASTRONOMY RESEARCH CLUSTERS						
		3-OW	3-XR	3-LF	3-OB	3-OS	3-SO	3-OP
A-1	HIGH-RESOLUTION OPTICAL SYSTEMS	C	I		C	C	C	C
A-2	ELECTRONIC IMAGE INTENSIFIERS	C			C	I	I	I
A-3	TELESCOPE OPERATION IN SPACE	C	C	I	C	C	C	C
A-4	ORBIT-TO-ORBIT SHUTTLE REQUIREMENTS	C	C	I	C	C	C	
A-5	ASSEMBLY AND ALIGNMENT OF HIGH-RESOLUTION TELESCOPES IN SPACE	C	C		C	C	C	I
A-6	DEVELOPMENTS FOR USE OF HIGH-RESOLUTION TELESCOPES (OPERATIONAL)	C		I	C	C	C	I
A-7	DEVELOPMENT OF USE OF PHOTOGRAPHIC FILM FOR SPACE ASTRONOMY	C	C		C	C	C	
A-8	HIGH-RESOLUTION OPTICAL TELESCOPES	C	I		C	C	C	
A-9	ELECTRONIC IMAGE INTENSIFIERS	I			I	I	I	I
A-10	ACQUISITION OF CELESTIAL TARGETS	C	C	C	C	C	I	C
A-11	HIGH PRECISION STELLAR PHOTOMETRY (PHOTO ELECTRIC)	I			I	I		C
A-12	COOLING OF SOLAR ASTRONOMY TELESCOPES	I				I	C	I
A-13	ACQUISITION AND TRACKING OF SOLAR TARGETS (DYNAMIC)	I			C	I	C	I

C - CRITICAL
I - IMPORTANT

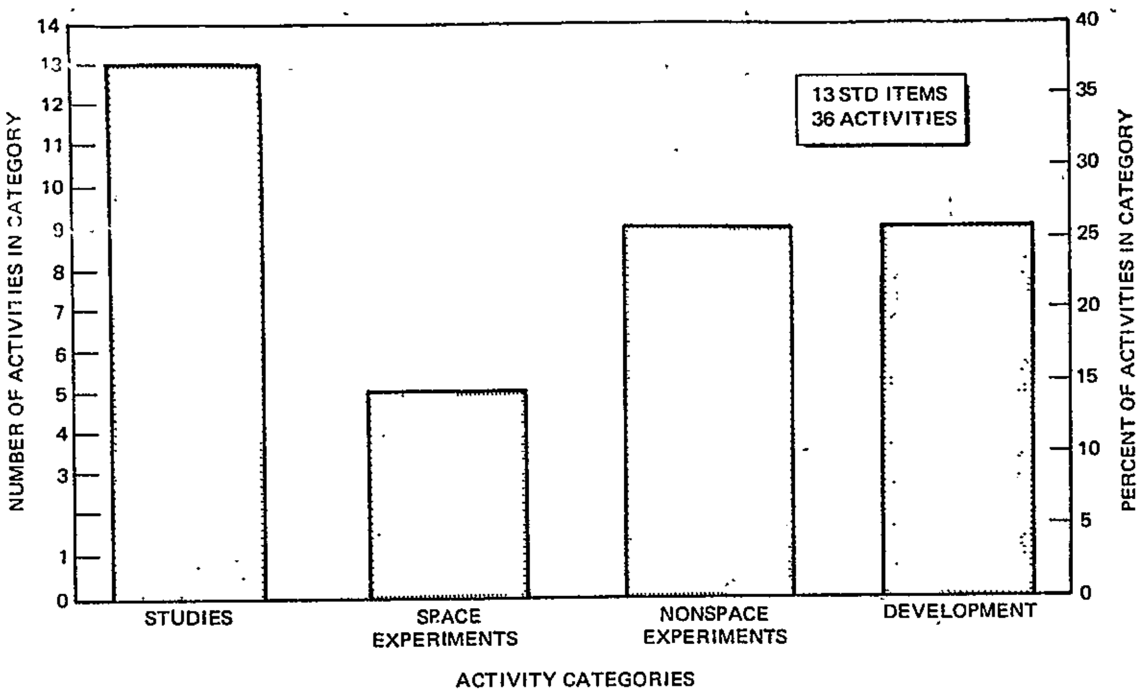


Figure 6-8. Space Astronomy-STD Activities Distribution.

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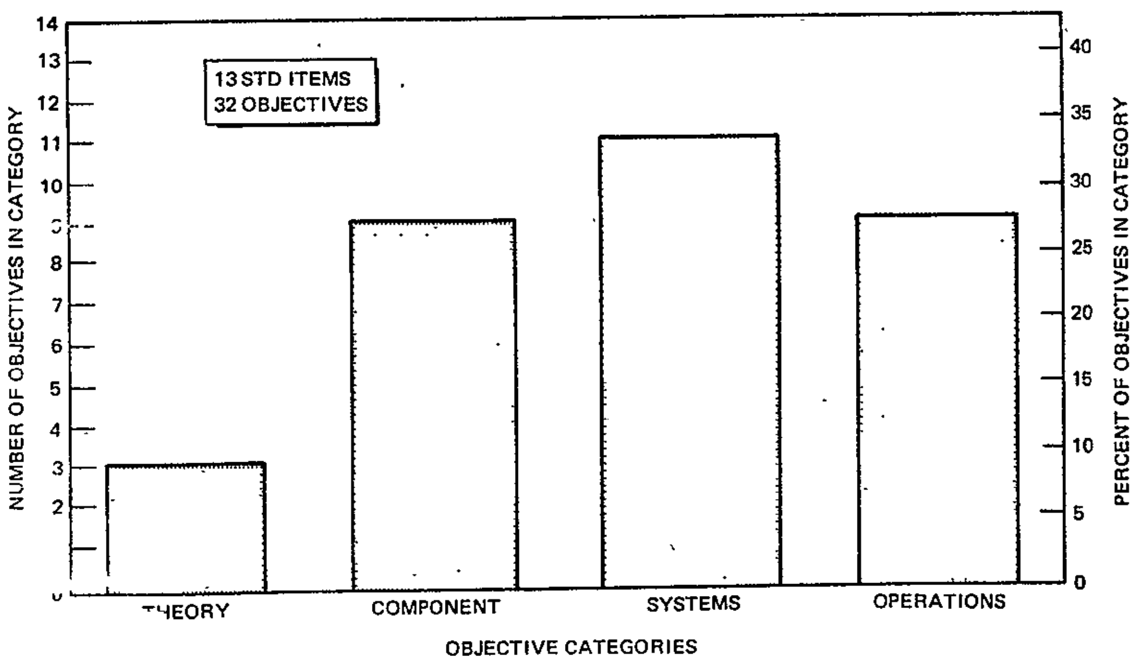

Figure 6-9. Space Astronomy-STD Objectives Distribution.

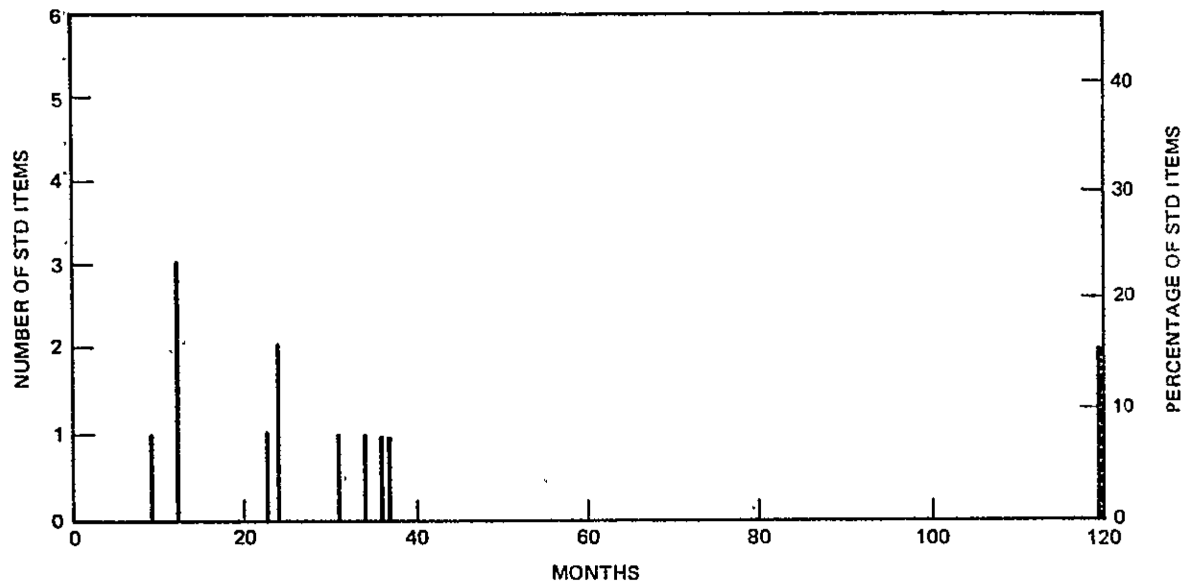

Figure 6-10. STD Time Estimates for Space Astronomy (13 STD Items).

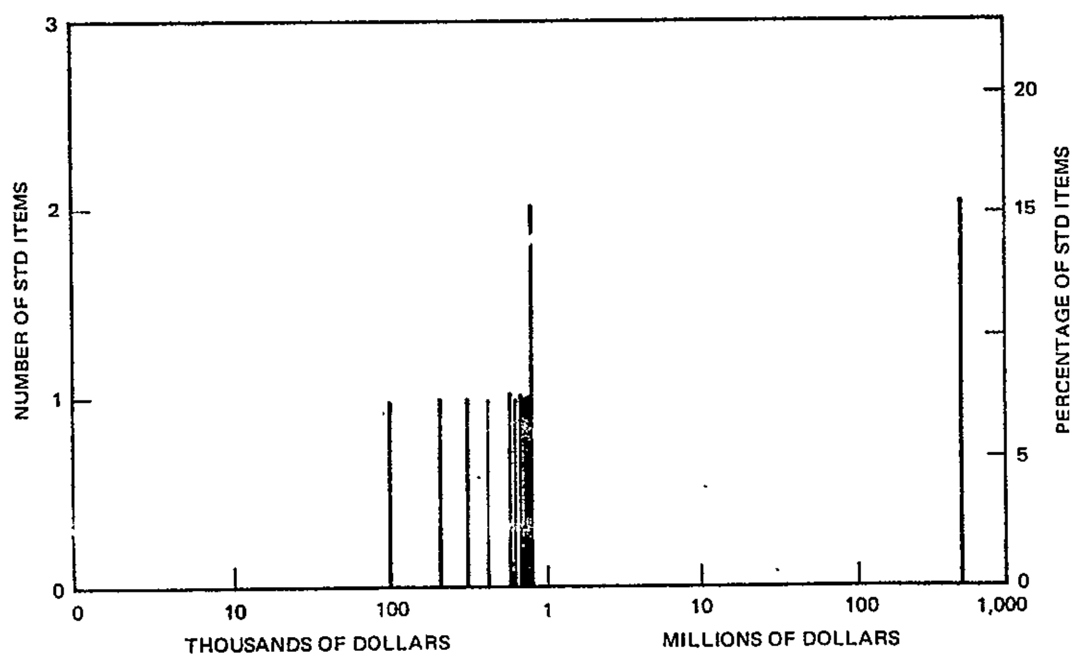

Figure 6-11. STD Maximum Cost Estimates for Space Astronomy (13 STD Items).

6.2.4 Space Physics

Taken in its broadest sense, Space Physics could encompass almost the entire Earth-orbital Program (e.g., astronomy, electromagnetics, meteorology, etc.). For obvious reasons, a more restrictive definition has been adopted. First, Space Physics activities have been restricted to three categories: studies of the space environment, examination of the interaction between spacecraft and the environment, and utilization of space for a physics laboratory. Next, critical issues were derived from the organized overviews pertaining to each of the above categories. Finally, after screening of the critical issues, three areas of research for Space Physics evolved. These areas, which are each described below, are the physics and chemistry laboratory, plasma physics, and high-energy cosmic ray physics.

1. Physics and Chemistry Laboratory - Eleven research clusters were identified in this area. These clusters, numbered 4-P/C-1 through 4-P/C-11, describe experiments designed to answer critical issues in the general areas of chemical reactions, space manufacturing, materials effects, liquid-vapor interactions in zero-gravity and superfluidity. Many of these experiments specify discrete, repeatable low-gravity levels in the range 10^{-2} to 10^{-6}g, a requirement unique to this area.

2. Plasma Physics - Four research clusters (4-PP-1, 4-PP-2, 4-PP-3 and 4-PP-4) were described and analyzed for STD requirements. The first related to spacecraft-environment interaction; the second related to energetic particle dynamics in the magnetosphere; the third to thermal plasma in the ionosphere and magnetosphere, and the last to auroral processes. Research cluster 4-PP-1 seeks answers to critical issues related to spacecraft wake characteristics, vehicle potentials, and spacecraft effluents. The perturbed region may extend for many kilometers; hence, subsatellites are required as probes. Subsatellites are also required for research cluster 4-PP-1, -2, and -3 for the delivery of barium canisters, high-energy electron guns; or high-power VLF sources to a region in space for the purpose of creating articial plasmas in the region. These latter experiments are denoted as either tracer or catastrophic experiments, depending upon the degree of the perturbation. For example, a small barium release may be used to study auroral electric fields, while a larger release may create an artificial aurora. The interaction of such releases upon other experiments, particularly those of Space Astronomy, must not be overlooked.

3. High-Energy Cosmic Ray Physics Laboratory - Research cluster description 4-CR completely describes ten separate cosmic ray experiments whose synopses (only) are given in descriptions 4-CR-1 through 4-CR-10. These ten experiments measure the following parameters related to high-energy cosmic rays:

Charge and energy spectra of cosmic ray nuclear component
Energy spectrum of high-energy primary electrons and positrons
Energy spectrum and spatial distribution of primary gamma rays
Long-lived heavy isotopes in cosmic rays
Antinuclei in cosmic rays
Quarks (stable, fractionally charged particles) in cosmic rays
Unknown particles in cosmic rays
Characteristics of albedo particles above 100 Mev.
Differential nucleon-nucleon cross sections at high energies
Differential spallation cross sections at high energies

Table 6-14 lists the Space Physics research clusters which were analyzed for STD requirements. With respect to research clusters 4-PP-2, 4-PP-3, and 4-PP-4, it was recognized that the essential equipment and techniques reouired for all three could be described most efficiently by dividing each into three parts. Some of the parts in different clusters (e.g., 4-PP-3-1 and 4-PP-2-1, Table 6-14) were essentially the same in terms of equipment and techniques required even though different research objectives were involved. Thus, in plasma physics, it was necessary to analyze only five unique descriptions of parts of research clusters, as shown in Table 6-14.

6.2.4.1. Requirements

Analysis of the 25 research clusters in Space Physics has led to the identification of 39 STD requirement items for which there is no existing applicable equipment or technique. These items are listed in Table 6-15 where the "P" prefix denotes Space Physics. Each item in the table corresponds to an STD requirement description presented in Appendix E. These STD items consists mostly of development of instruments and apparatus together with study of operational techniques for this new equipment.

6.2.4.2 Data Summary

Although each of the STD items given in Table 6-15 was derived in response to requirements from a specific Space Physics research cluster, it is important that commonality outside the parent cluster and, indeed, outside the study area, be identified. To this end, a commonality matrix was created that lists the Space Physics STD items versus the Space Physics research clusters. For each STD item, an importance rating is shown relative to each research cluster by entering either a C (for critical) or an I (for important) at the appropriate intersection on the matrix. The Space Physics commonality matrix is shown in Table 6-16. It must be emphasized that the importance rating of an STD item is determined from this matrix and not from the rating given on the research cluster description form, which relates only to the research cluster being considered at the time the STD requirement is identified. That is, it is quite possible to derive an STD item rated important with respect to the originally considered research cluster and then later find that the same STD item is critical with respect to another cluster. Commonality outside the Space Physics study area is given in Table 6-25 in the program synthesis discussion.

Further analysis shows that 24 of the 39 STD items (60 percent) are rated critical to at least one research cluster requirement. From the confidence ratings on the STD requirement descriptions (Appendix E), it is found that 33 of these 39 items are given a high confidence rating with the remaining 6 rated medium. These confidence ratings represent solely the opinion of the compiler, however.

Continuing with the analysis of the data given in Appendix E, distributions of the STD activities and objectives were generated and are shown in Figures 6-12 and 6-13. These data are the summaries of items 5 and 6 of the STD requirement description form. Since more than one box could be checked in answer to this question, there are more activities and objectives than there are STD items.

Of the 66 activities, 32 (48 percent) were studies. Stated differently, 82 percent of the 39 Space Physics STD items called for a study. These studies included finding the best way to conduct physics experiments in zero-gravity, assessing alternate concepts for achieving a particular advancement, evaluating the effects of one experiment upon another, and conducting theoretical research

Table 6-14

SPACE PHYSICS RESEARCH CLUSTERS

Number	Research Cluster Title
4-P/C-1	Effect of the Space Environment on Chemical Reactions
4-P/C-2	Shape and Stability of Liquid-Vapor Interfaces
4-P/C-3	Boiling and Convective Heat Transfer in Zero Gravity
4-P/C-4	Effect of Zero Gravity on the Production of Controlled-Density Materials
4-P/C-5	Effect of Electric and Magnetic Fields on Materials
4-P/C-6	Use of Zero Gravity to Produce Materials Having Superior Physical Characteristics
4-P/C-7	Improvements of Materials by Levitation Melting
4-P/C-8	Effect of Zero Gravity on the Production of Films and Foils
4-P/C-9	Effects of Zero Gravity on Liquid Release, Size Distribution of Liquid Drops
4-P/C-10	Capillary Flow in Zero Gravity
4-P/C-11	Behavicr of Superfluids in the Weightless State
4-PP-1	Spacecraft Environment Interaction
4-PP-2	Energetic Particle Dynamics in the Magnetosphere (3 parts)
4-PP-2-1	Use of Alkali Metal Clouds as a Space Diagnostic
4-PP-2-2	Use of Electron Beams as a Space Diagnostic
4-PP-2-3	VLF Wave Propagation
4-PP-3	Thermal Plasma in the Ionosphere and Magnetosphere (3 parts)
4-PP-3-1	(Essentially the same as 4-PP-2-1)
4-PP-3-2	(Essentially the same as 4-PP-2-3)
4-PP-3-3	RF Plasma Resonance Studies
4-PP-4	Auroral Processes (3 parts)
4-PP-4-1	(Essentially the same as 4-PP-2-1)
4-PP-4-2	(Essentially the same as 4-PP-2-2)
4-PP-4-3	(Essentially the same as 4-PP-2-3)
4-CR	Cosmic Ray and High-Energy Physics Laboratory

TABLE 6-15

SPACE PHYSICS STD LIST (page 1 of 2)

STD Number	STD Title
P-1	Mass Spectrometer
P-2	Gas Chromatograph
P-3	Pyrometer
P-4	Apparatus for Liquid-Vapor Studies
P-5	Low-Gravity Accelerometer
P-6	Low-Gravity Isolation Mounts
P-7	Crystal Growing Apparatus
P-8	Zone Refining Apparatus
P-9	Production of Hard Vacuums
P-10	Contamination by Physics Apparatus
P-11	Melting Apparatus
P-12	Sample Centering Device
P-13	Film Drawing Experiments
P-14	Optimum Material Heating
P-15	Cosmic Ray Experiment Package
P-16	Laser Holograph
P-17	Contaminant-Proof EC & LS System
P-18	Heat Transfer Chamber
P-19	Superconducting Magnets
P-20	Integrated Physics Apparatus
P-21	Wicking Apparatus
P-22	Gravity-Level Control
P-23	Heat Transfer Apparatus
P-24	Apparatus for Controlled-Density Materials Study
P-25	Film-Video Tape Trade Study
P-26	Onboard Film Processing
P-27	Transition Radiation Detector
P-28	Superconducting Materials
P-29	Cryogenic Systems

TABLE 6-15

SPACE PHYSICS STD LIST (page 2 of 2)

STD Number	STD Title
P-30	Plasma Physics Subsatellites
P-31	DC Electric Field Measurements
P-32	Plasma Diagnostic Techniques
P-33	Barium Cloud Apparatus
P-34	Intense Electron Sources
P-35	Research in Plasma Physics
P-36	Apparatus for Superfluidity Tests
P-37	Dewar Viewport Studies
P-38	Cryogenic Remote Handling
P-39	Superfluid Research

studies. Development accounted for 29 percent of the activities. This is not unexpected, since many of the physics experiments call for unique specialized apparatus, almost none of which exists as flight-qualified hardware.

Turning to the STD objectives, one finds that systems dominate the distribution. If components are also included in order to avoid the semantic difficulties in these terms, then more than half the total objectives are accounted for. Thus, in Space Physics, the STD emphasis is on "things" (new types of apparatus, for the most part). The tasks to be done with these are not unduly demanding; hence the low operations score. The relatively low percentage of theoretical objectives in Space Physics is a natural result of the nature of the Space Physics program. It is primarily experimental in nature, oriented toward verifying or extending certain well developed theories. However, the theoretical studies identified are broad in scope and crucial to the success of the research clusters to which they apply.

Figures 6-14 and 6-15 show the time and cost distributions of the Space Physics STD items based upon the estimates supplied by the compliers. These figures show that 90 percent of the STD items require less than 36 months for completion,

TABLE 6-16.

SPACE PHYSICS COMMONALITY MATRIX

STD NUMBER	STD TITLE	SPACE PHYSICS RESEARCH CLUSTERS																
		4-P/C-1	4-P/C-2	4-P/C-3	4-P/C-4	4-P/C-5	4-P/C-6	4-P/C-7	4-P/C-8	4-P/C-9	4-P/C-10	4-P/C-11	4-CR	4-PP-1	4-PP-2-1	4-PP-2-2	4-PP-2-3	4 PP-3-3
P-1	MASS SPECTROMETER	I																
P-2	GAS CHROMATOGRAPH	I			I													
P-3	PYROMETER	C						C										
P-4	APPARATUS FOR LIQUID/VAPOR STUDIES		C															
P-5	LOW-G ACCELEROMETER		C	C	I	I	C	C			C	C						
P-6	LOW-G ISOLATION MOUNTS	I	C	C	C	C	C	C	I	I	C	C						
P-7	CRYSTAL GROWING APPARATUS						C											
P-8	ZONE REFINING APPARATUS						C											
P-9	PRODUCTION OF HARD VACUUMS						C		I									
P-10	CONTAMINATION BY PHYSICS APPARATUS						I		I						I			
P-11	MELTING APPARATUS				I	I	I	C										
P-12	SAMPLE CENTERING DEVICE					I	I	I										
P-13	FILM DRAWING EXPERIMENTS								C									
P-14	OPTIMUM MATERIAL HEATING				I	I	I	I	I									
P-15	COSMIC RAY EXPERIMENT PACKAGE												C					
P-16	LASER HOLOGRAPHY									I								
P-17	CONTAMINANT - PROOF EC&LS SYSTEM	C	C	C	C	C	C	C	C	C	C							
P-18	HEAT TRANSFER CHAMBER					C												
P-19	SUPERCONDUCTING MAGNET					I						I	I					
P-20	INTEGRATED PHYSICS APPARATUS	I	I	I	I	I	I	I	I	I	I	I						
P-21	WICKING APPARATUS										C							
P-22	G-LEVEL CONTROL		I	I			I	C			C	C						
P-23	HEAT TRANSFER APPARATUS			C														
P-24	APPARATUS FOR CONTROLLED DENSITY MATERIAL STUDY				C													
P-25	FILM-VIDEO TAPE TRADE STUDY	I	I	I				I		I	I	I			I	I		
P-26	ON-BOARD FILM PROCESSING	I	I	I				I		I		I	I		I	I		
P-27	TRANSITION RADIATION DETECTOR												I					
P-28	SUPER CONDUCTIVE MATERIALS					I						I	I					
P-29	CRYOGENIC SYSTEMS		I			I						I	C					
P-30	PLASMA PHYSICS SUBSATELLITE													C	C	C	C	C
P-31	DC ELECTRICAL FIELD MEASUREMENT													I				
P-32	PLASMA DIAGNOSTICS														I	I	I	
P-33	BARIUM CLOUD APPARATUS														C			
P-34	INTENSE ELECTRON SOURCE															I		
P-35	RESEARCH IN PLASMA PHYSICS											I		C	C	C	C	C
P-36	APPARATUS FOR SUPERFLUIDITY											C						
P-37	DEWAR VIEWPORT STUDIES		I	C								C						
P-38	CRYOGENIC REMOTE HANDLING		I	I								C						
P-39	SUPERFLUID RESEARCH											C						

C – CRITICAL, I – IMPORTANT

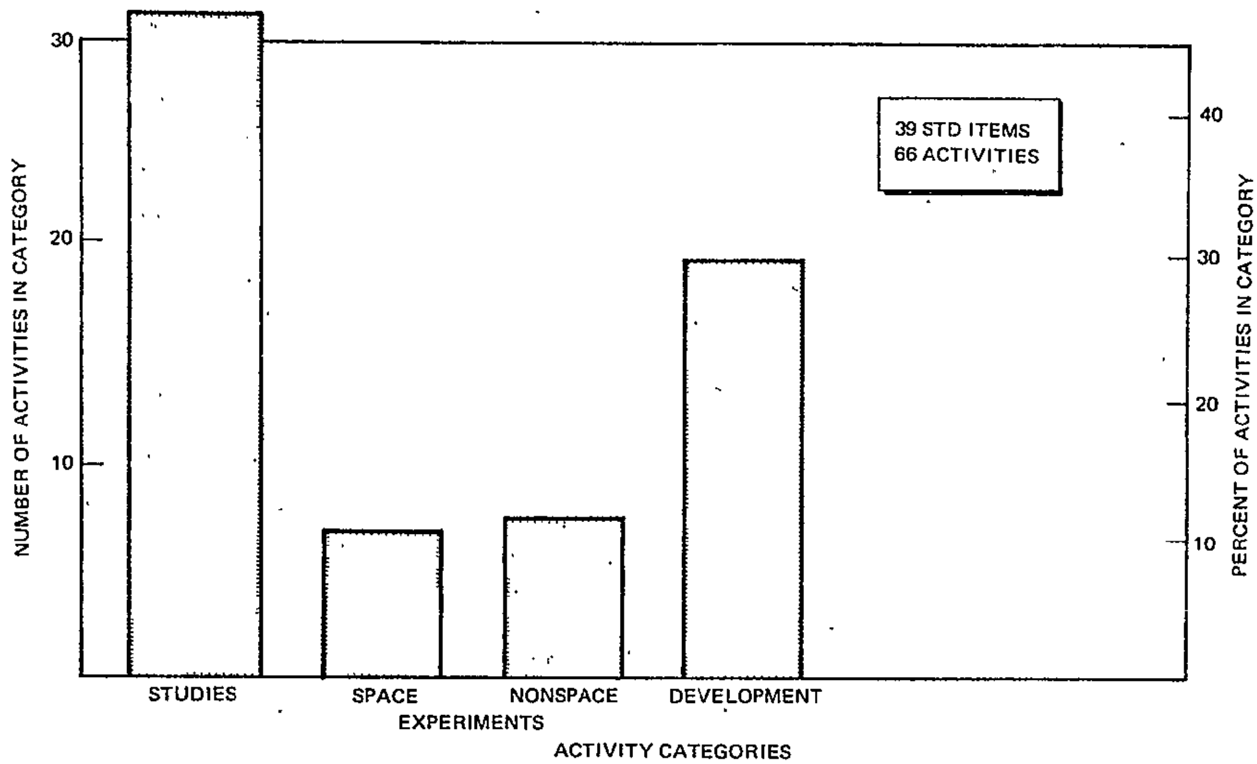

Figure 6-12. Space Physics - STD Activities Distribution.

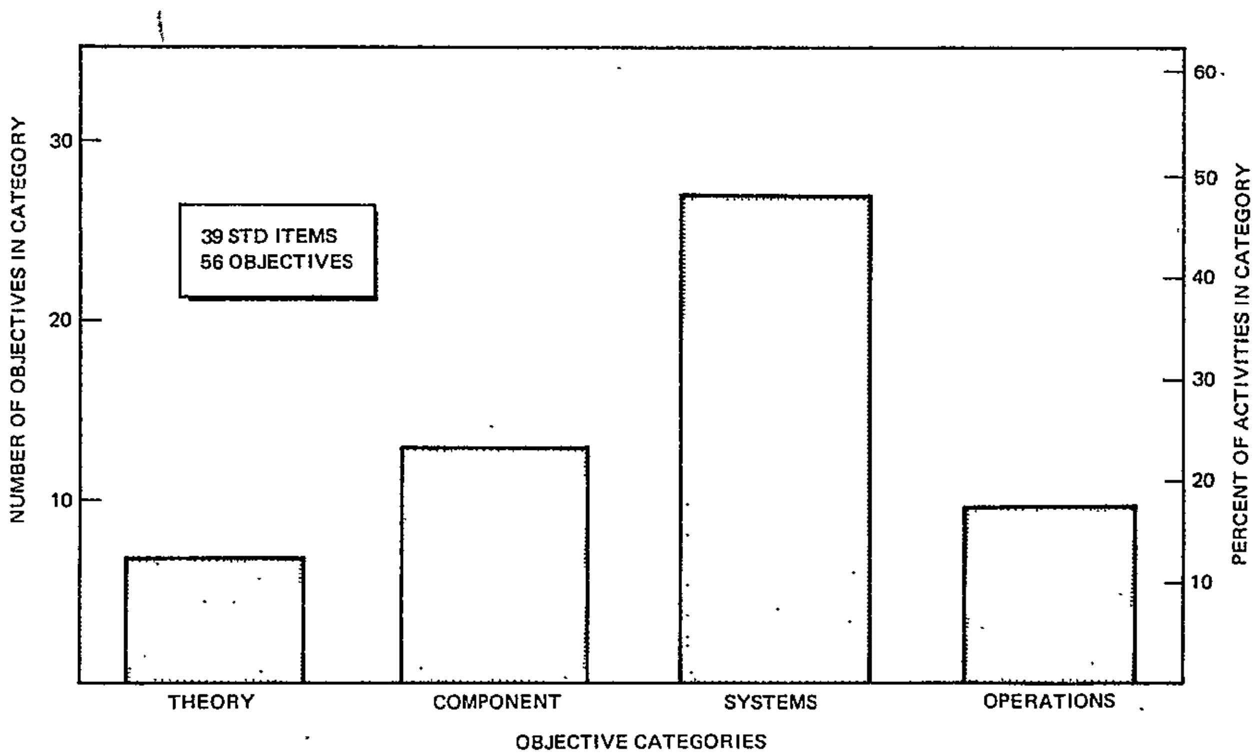

Figure 6-13. Space Physics - STD Objectives Distribution.

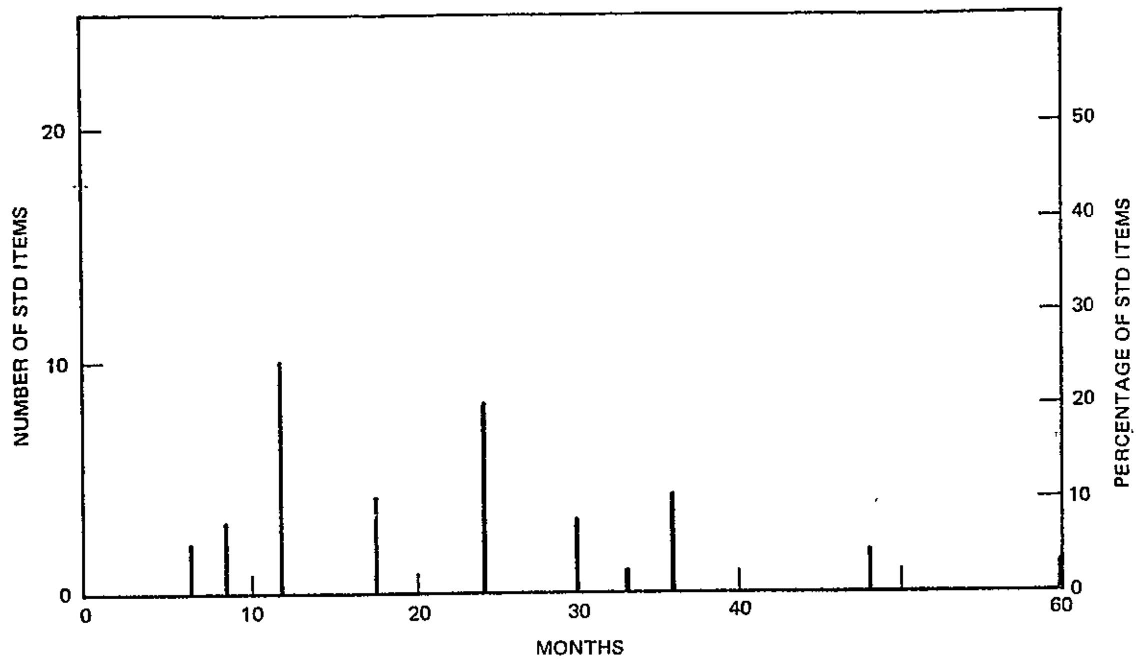

Figure 6-14. STD Time Estimates for Space Physics (39 STD Items).

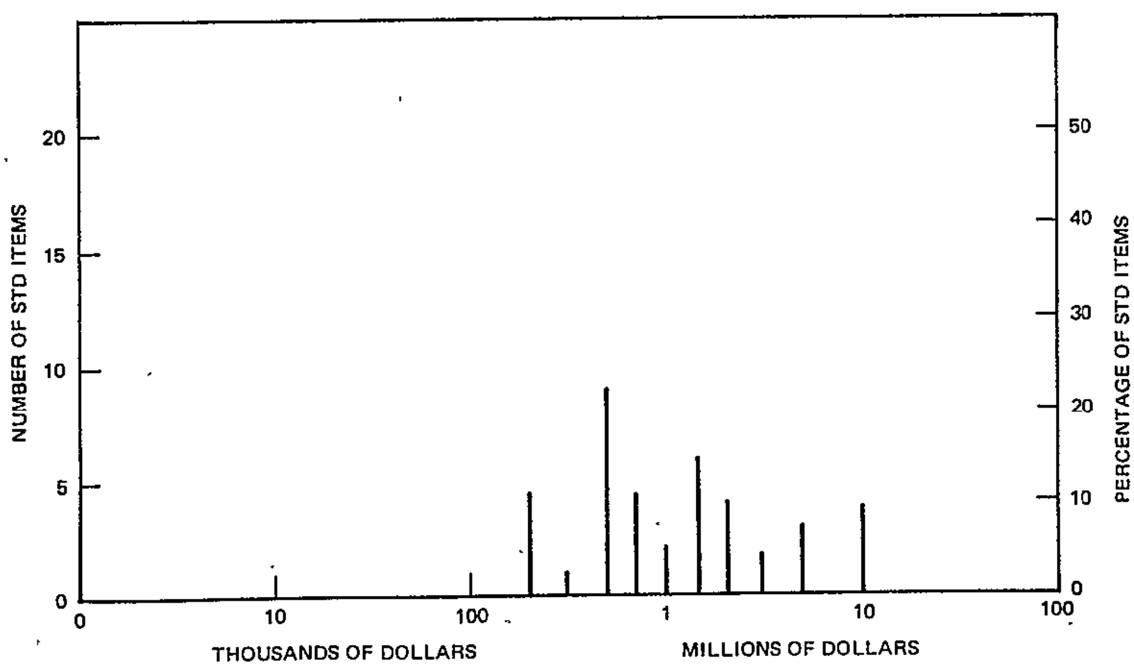

Figure 6-15. STD Cost Estimates for Space Physics (39 STD Items).

with 75 percent of them costing between \$200,000 and \$2 million. However, these are only crude estimates. Furthermore, STD items taken individually do not necessarily make reasonable work packages. Subsection 6.4 addresses the problem of forming logical work packages (groups of STD items) based upon data such as that above.

6.2.4.3. Conclusions

The STD items derived from the Space Physics are seen to consist largely of new instruments and apparatus for the conduct of the physics experiments. Examples include P-1 (Mass Spectrometer), P-2 (Gas Chromatograph), P-11 (Melting Apparatus), and P-36 (Apparatus for Superfluidity Tests). The STD analysis has also defined a great many studies related to the optimal operation of this apparatus. These items include:

1. Item P-14, Optimum Material Heating. - The Physics and Chemistry experiments have large heating requirements. Large ovens are proposed with temperatures up to 3,000°C for melting aluminum, glass, etc., which create an equivalent electrical load in excess of 20 kilowatts. A study is required to evaluate the various means of supplying this heat (electrical, laser or electron bombardment, solar). This study should also consider crew safety and spacecraft interface.
2. Item P-30, Plasma Physics Subsatellites. - Besides the obvious requirement for vehicle development, this STD item also calls for a study to integrate the subsatellite operations with those of the orbital research facility and to specify the number and proper deployment, including orbit keeping, of the subsatellite constellations.

In addition, some STD items recognize subtle but crucial requirements which are technologically challenging. These include:

1. Item P-9, Production of Hard Vacuums. - Because of the effluent-cloud which will be present around a large orbital facility, the vacuum in the immediate vicinity may not be sufficient for some Space Physics requirements. Studies and space experiments are required to evaluate alternate concepts for overcoming this problem (extended vent pipes, pumps, modules); to measure the effluent effects for various vehicle configurations; and to theoretically determine diffusion rates and electric charge effects.
2. Item P-31, DC Electric Field Measurement. - A device is required to measure DC electric fields as low as 1 mv/m. This alone is a major development requirement; however, the effects of contact potentials and plasma coupling arising from the space environment further complicate the problem.

Some STD items have very broad impact, not only within Space Physics, but with respect to other study areas as well. These items include:

1. Item P-10, Contamination by Physics Apparatus. - This is primarily a systems and operations study related to the deleterious effects of hot, outgassing physics apparatus being operated outside the space facility. The importance to Space Astronomy, for example, is obvious.
2. Item P-17, Contaminant-Proof EC & LS System. - Many physics and chemistry laboratory experiments require handling of hot, noxious fluids, molten metals, fuel vapors, etc., none of which can be tolerated in today's EC & LS systems. In addition, the lack of gravity introduces some unique problems: What happens if molten aluminum escapes its crucible? How is a laboratory cleaned up after a fire is extinguished?
3. Item P-25, Film-Video Tape Trade Study. - Most physics experiments (and many more outside Space Physics) require image recording for subsequent photometric or time and motion analysis. A careful study is needed in this STD item to assess the relative merits of photographic film and video recording for meeting these requirements. This is a rather straightforward requirement but a great many research clusters are affected.
4. Item P-29, Cryogenic Systems. - Requirements for cryogenic liquids are found in every study area: in Manned Spaceflight Capability for condensing experiments, in Space Biology for tissue preservation, in Space Astronomy and Earth Observations for film storage, in Space Physics for cryogenic fluid behavior studies (plus many others), and in Communications and Navigation for use in cooled parametric amplifiers. A large, central source of cryogenic fluid is clearly indicated. This STD item calls for studies to determine the techniques for maintenance of large quantities of cryogenics (onboard refrigerators, resupply, etc.) and for efficient management of the central cryogenic system to serve the many users effectively.

6.2.5 Communications and Navigation

Unlike other disciplines, where scientific understanding is the primary objective, the communications and navigation sciences are dedicated to providing functional user services. For this reason, the overview analysis was concerned with the application of space technology to fulfill user needs for information exchange over large distances. The central theme of Communications and Navigation, as shown in Figure 6-16, involves applications, component development, and study of the free-space and atmospheric environment.

For Communications, the advanced systems are extensions of existing capabilities, through growth and augmentation, by employing space to improve customer services.

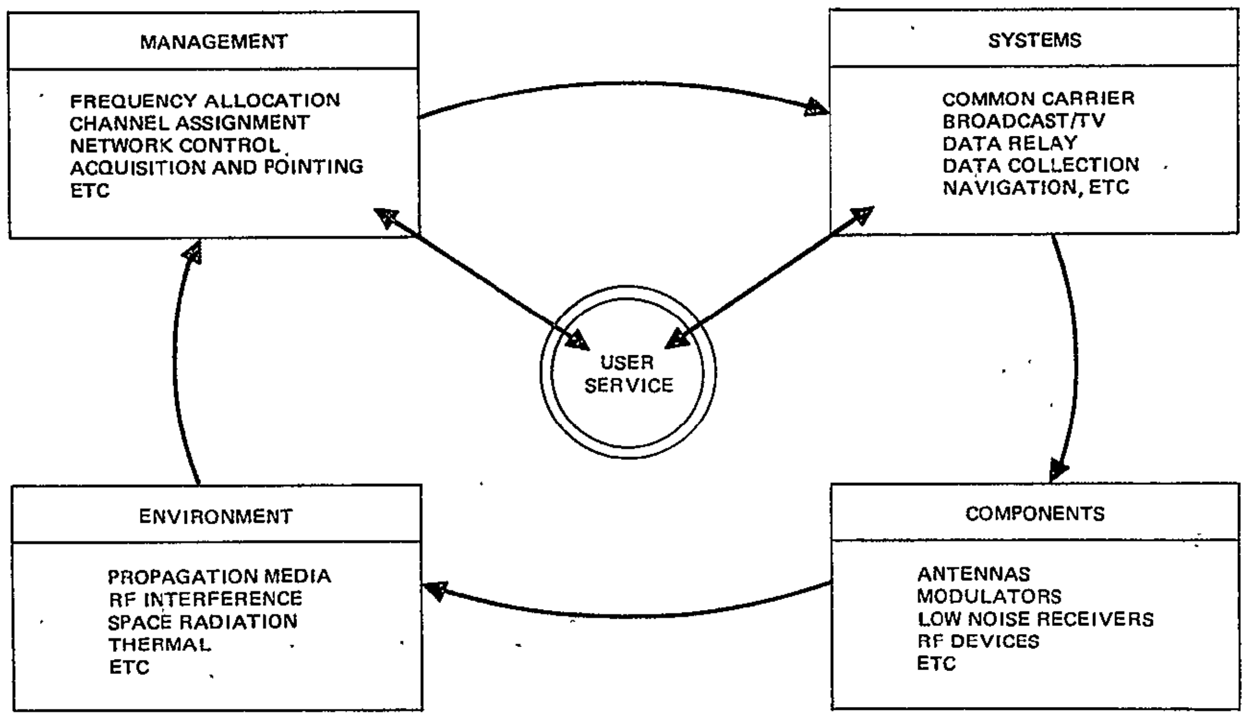

Figure 6-16. Communications and Navigation Central Theme.

The Navigation services involve not only communications but position location, surveillance, and control of high-speed transportation vehicles.

It follows, then to seek answers to these questions:

1. Who are the users and how may they be categorized?
2. What services are required, or desired, by these users?
3. How may space technology provide these services?
4. Can decisions be made as to the best system approach?
5. Is the required technology available?
6. Is sufficient information available for engineering design?

As might be suspected, there are few sources of technological forecasting available for answers. In this study it was decided to divide the Communications discipline into applications, research and development, and resource management. The objectives and critical issues relating to applications cover various systems techniques; research and development considers the propagation medium, transmission techniques, and component technology; and resource management deals with allocation and use of spectra with emphasis on expansion into the millimeter and laser spectra. The Navigation objectives subdivide into three classes, marine and airborne needs, space needs, and the interface between these classes; i.e., launch and reentry needs. (Any navigation critical issues pertinent to communications are found in that discipline.)

To satisfy these critical issues, five areas of research were derived, containing a total of 16 research clusters. The first four areas pertain to Communications; the last to Navigation. They are as follows:

- Noise (N) - Experiments dealing with receiver noise and radio frequency interference.
- Propagation (P) - Experiments dealing with the propagation of electromagnetic waves between transmitting and receiving antennas.
- Test Facility (TF) - Activities and operations in a general purpose test facility.
- Communications Systems (CS) - Demonstration and assessment of systems designed for exploitation of new frequency bands in the EM spectrum (here taken to be MM waves and optical frequencies).
- Navigation Systems (NS) - Evaluation of techniques for and accuracy of elements of advanced satellite navigation systems.

The 16 research clusters derived from these research areas are given in Table 6-17.

6.2.5.1. Requirements

A total of 30 STD items, listed in Table 6-18, were derived for Communications and Navigation. Items C-1 through C-6 and C-22 through C-30 relate to Communications, while C-7 through C-21 relate to Navigation. Each of the STD items listed in the table corresponds to an STD requirement description, found in Appendix E.

6.2.5.2. Data Summary

In order to evaluate the impact of STD items upon all of the research clusters within the Communications and Navigation discipline, a commonality matrix was created which lists STD items versus the Communications and Navigation research clusters. For each STD item, an importance rating is shown relative to each cluster by entering either a "C" for critical or an "I" for important at the appropriate intersection on the matrix. Table 6-19 is the commonality matrix for Communications and Navigation. As stated in Subsection 6.2.4.2, the importance rating of an STD item must be ascertained solely on the basis of the rating given on the commonality matrix and not just on the entrv on the STD description form.

The entries on the Communications and Navigation commonality matrix are seen to lie largely on the diagonal, indicating that little cross-experiment commonality exists. This arises from the extremely specialized nature of the STD items which were derived.

Figure 6-17 shows the distribution of activities (studies, experiments to define capabilities or developments) in Communications and Navigation. The equipment-oriented nature of this study area is reflected in the large percentage of development that is found (56 percent). Almost 40 percent of the activities are studies and, although not shown here (see Subsection 6.3) the majority of these studies are systems studies. A very low percentage of the activities relate to experiments for determination of capabilities. Thus, the activities

Table 6-17

COMMUNICATIONS AND NAVIGATION RESEARCH CLUSTERS

Number	Research Cluster Title
5-N-1	Terrestrial Noise Measurements
5-N-2	Noise Source Identification
5-P-1	Ionospheric Propagation Measurements
5-P-2	Tropospheric Propagation Measurements
5-P-3	Plasma Propagation Measurements
5-P-4	Multipath Measurements
5-TF-1	Space Deployment and Calibration
5-TF-2	Demonstration and Test
5-CS-1	MM Wave Demonstration
5-CS-2	Optical Frequency Demonstration
5-NS-1	Satellite Navigation Techniques for Terrestrial Users
5-NS-2	Laser Ranging
5-NS-3	Autonomous Navigation Systems for Space
5-NS-4	Surveillance Systems
5-NS-5	Collision Avoidance Systems Techniques
5-NS-6	Search and Rescue Systems

in communications and navigation relate largely to developing and qualifying hardware, and carrying out the necessary systems studies.

The distribution of the objectives to which the above activities apply is given in Figure 6-18. Again avoiding the unclear semantics regarding "systems" and "components," it is clear that most objectives relate to things, in this case communications hardware. Since the goals of Communications and Navigation are user-oriented, it is not surprising that theoretical objectives scored low. (Of the two theoretical studies identified, both related to computer software.) Operations also scored low, reflecting the relatively straightforward crew/operator tasks needed in the performance of the experiments.

Table 6-18

COMMUNICATIONS AND NAVIGATION STD LIST

STD Number	STD Title
C-1	94 GHz Amplitude and Phase Measurement System
C-2	MM Waves Experiment Plan
C-3	MM Waves Experiment Package
C-4	Broadband Modulators
C-5	High Speed Correlator
C-6	Laser Telescope Alignment
C-7	Improved Satellite Tracking
C-8	Subsatellite for Navigation
C-9	Transponders for Navigation Satellites
C-1[illegible]	Data Processing Software
C-1[illegible]	Satellite Position Determination
C-1[illegible]	Laser Radar Development
C-1[illegible]	Autonomous Navigation Sensors
C-1[illegible]	Improved Position Determination
C-1[illegible]	Software Development for Autonomous Navigation
C-1[illegible]	Subsatellites for Surveillance
C-1[illegible]	Transponders for Surveillance Systems
C-1[illegible]	Data Processing Software
C-1[illegible]	Collision Avoidance Hardware
C-2[illegible]	Emergency Location Signal Detectors
C-2[illegible]	Software Development for Location Methods
C-2[illegible]	Low Noise Receivers
C-2[illegible]	Computer Software for Noise Measurements
C-2[illegible]	Noise Source Identification Plan
C-2[illegible]	Digital Ionosounder
C-26	Higher Efficiency RF Transmitters
C-27	High Power RF Transmitters
C-28	Computer Software for Propagation Experiments

TABLE 6-19. COMMUNICATIONS AND NAVIGATION COMMONALITY MATRIX

STD NUMBER	STD TITLE	COMMUNICATIONS AND NAVIGATION RESEARCH CLUSTERS													
		5-CS-1	5-CS-2	5-N-1	5-N-2	5-P-1	5-P-2	5-P-3	5-P-4	5-NS-1	5-NS-2	5-NS-3	5-NS-4	5-NS-5	5-NS-6
C-1	94GHz AMPLITUDE AND PHASE MEASUREMENT	C													
C-2	MM WAVES EXPERIMENT PLAN	C													
C-3	MM WAVES EXPERIMENT PACKAGE	C													
C-4	BROADBAND MODULATORS	C													
C-5	HIGH-SPEED CORRELATOR	I													
C-6	LASER TELESCOPE ALIGNMENT		I												
C-7	IMPROVED SATELLITE TRACKING									I		I			
C-8	NAVIGATION SUBSATELLITE									C			I		
C-9	TRANSPONDERS									I			I		
C-10	DATA PROCESSING SOFTWARE									C			I		
C-11	SATELLITE POSITION DETERMINATION									I		I	I		
C-12	LASER RADAR										C				
C-13	AUTONOMOUS NAVIGATION SENSORS											C			
C-14	IMPROVED POSITION DETERMINATION									I		I			
C-15	SOFTWARE DEVELOPMENT											C			
C-16	SURVEILLANCE SUBSATELLITE									I			C		
C-17	TRANSPONDERS									I			I		
C-18	DATA PROCESSING SOFTWARE									I			I		
C-19	COLLISION AVOIDANCE HAREWARE													C	
C-20	EMERGENCY LOCATION SIGNAL DETECTOR									I					I
C-21	SOFTWARE DEVELOPMENT														I
C-22	LOW-NOISE RECEIVER			C											
C-23	COMPUTER SOFTWARE			I											
C-24	NOISE SOURCE IDENTIFICATION PLAN				C										
C-25	DIGITAL IONOSOUNDER					I									
C-26	HIGH-EFFICIENCY RF TRANSMITTER							I							
C-27	HIGH-POWER RF TRANSMITTER							C							
C-28	COMPUTER SOFTWARE								I						
C-29	SELF-STEERING PHASED ARRAY								I						
C-30	OPTICAL COMMUNICATION SYSTEM		C												

C — CRITICAL
I — IMPORTANT

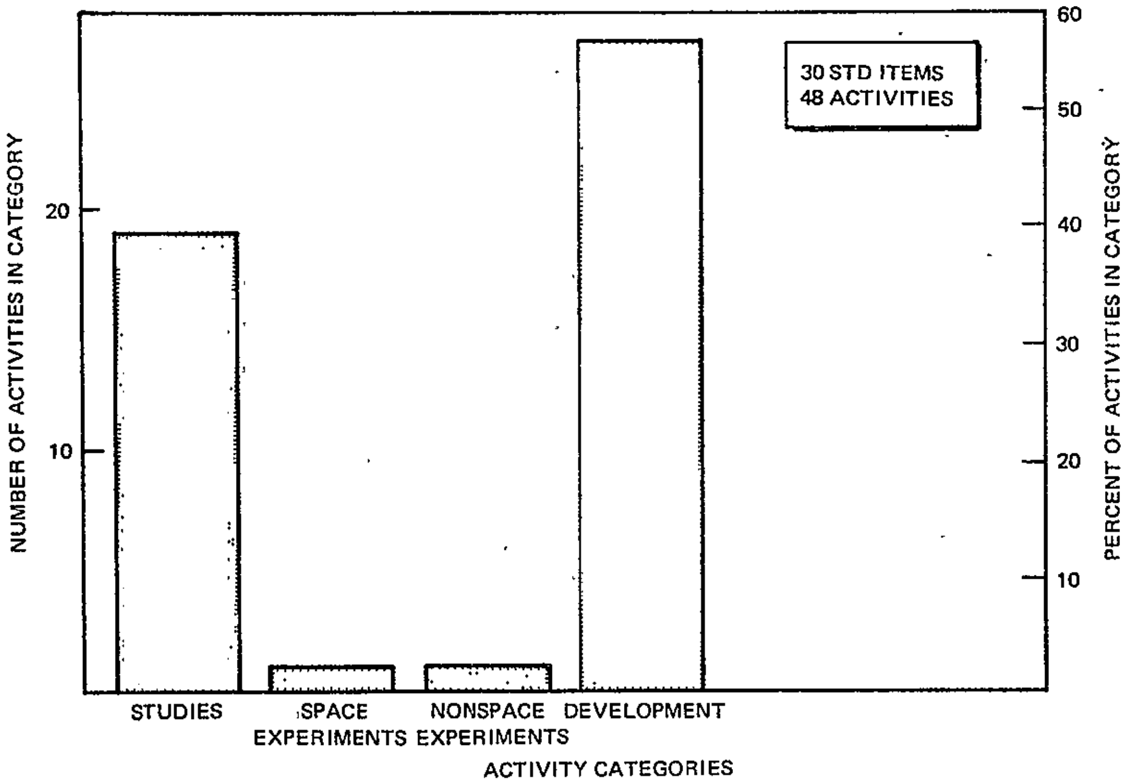

Figure 6-17. Communications and Navigation - STD Activities Distribution

STD Number	STD Title
C-29	Self-Steering Phased Array Antenna
C-30	Optical Communications System

Time and cost estimates are given in Figures 6-19 and 6-20. Inspection of these figures reveals that 87 percent of the STD items are estimated to require 36 months or less for completion. One item, C-6 (Improved Long-Term Optical Alignment of Laser Telescopes) is estimated to require 7 years due to the broad scope and uncertainties of the required efforts.

6.2.5.3. Conclusions

The user-oriented nature of Communications and Navigation is reflected in STD items which were derived for this study area. Most of the STD activities identified called for development of specialized communications hardware, or were systems studies related to such development. A particularly challenging example is STD No. C-1, the 94 GHz Amplitude and Phase Measurement System which is required for the millimeter wave experiments in Research Cluster 5-CS-1. This system is clearly beyond the present state-of-the-art, which is limited to 18 GHz for automatic systems. A related item, No. C-5, Development of a High-Speed Correlator, also represents a first-order technological challenge.

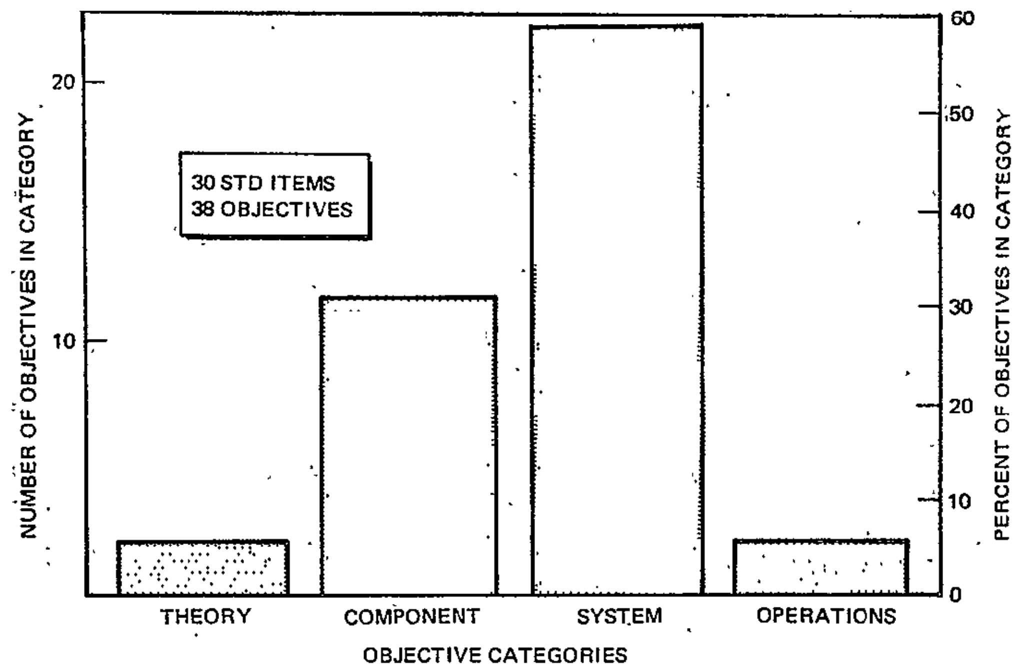

Figure 6-18. Communications and Navigation - STD Objectives Distribution

The research cluster related to autonomous navigation, 5-NS-3, generated some advanced STD requirements including Autonomous Navigation Software Development, Item No. C-15; Improved Satellite Position Determination, Item No. C-14, which calls for an order-of-magnitude increase in capability; and Development of Autonomous Navigation Sensors, Item No. C-13. This latter item mentions several required improvements (in star trackers, radars, etc.) but the most far-reaching and technologically difficult is the landmark tracker. The operation of landmark trackers depends on pattern-recognition which is still in a very early state of development.

The laser was significant in three STD items, C-6 (Improved Long-Term Optical Alignment of Laser Telescopes), C-12 (Development of Space-Qualified Laser Radar Equipment), and C-30 (Development and Qualification of Optical Communications Systems for Atmospheric Transmission Measurements). These items, besides being beyond the current state-of-the-art, have much in common with another study area, Space Astronomy. The techniques required for telescope pointing, target acquisition and stabilization are the same for both. This cross-discipline commonality is treated further in Subsection 6.4.1.

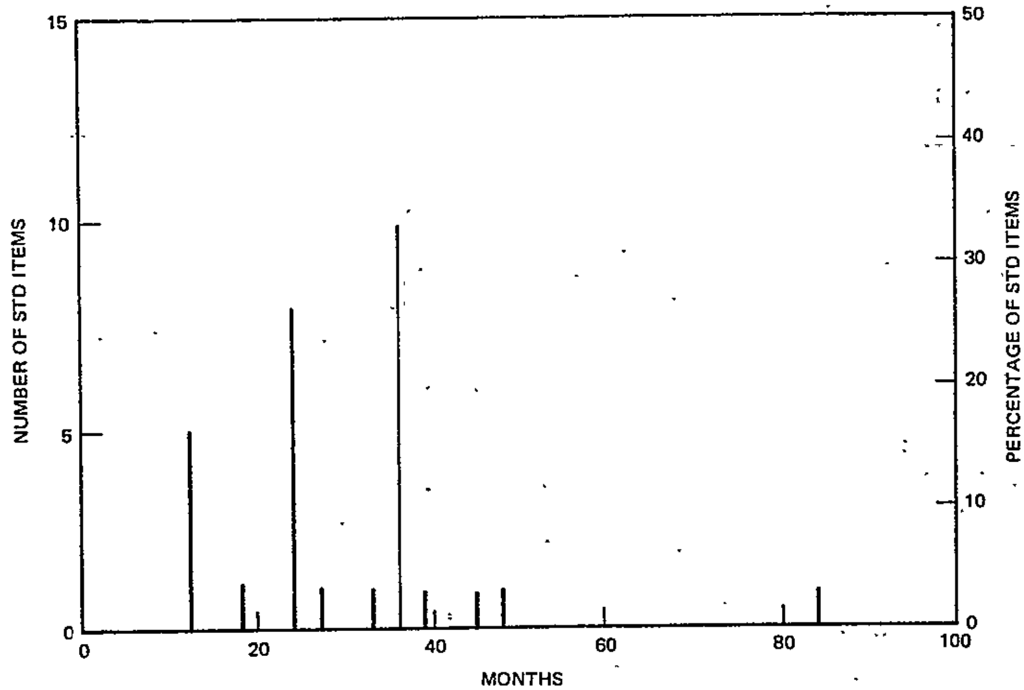

Figure 6-19.
STD Activity Time Estimate for Communications and Navigation (30 STD Items).

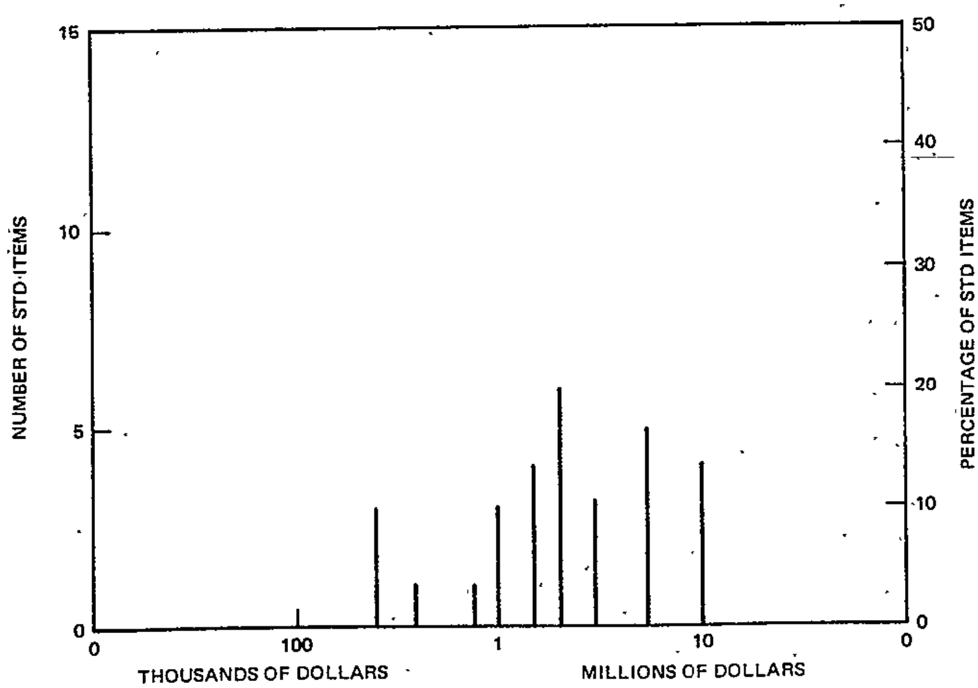

Figure 20.
STD Activity Cost Estimates for Communications and Navigation (30 STD Items).

Additional cross-discipline commonality is found between STD items C-8 (Development of Subsatellites for Navigation Experiments) and C-16 (Development of Subsatellites for Surveillance Systems) in Communications and Navigation and the subsatellite STD requirements in Space Physics. Again, Subsection 6.4.2 treats this in greater detail.

6.2.6. Earth Observations

The discipline of Earth Observations is comprised of seven subdisciplines: Agriculture/Forestry, Earth Physics, Geography/Cartography, Geology, Hydrology, Meteorology and Oceanography. Within these categories, a total of 34 research clusters was derived from 650 critical issues. These research clusters are presented in Table 6-20 with their identifying numbers. Note the research cluster numbers are keyed to their respective subdisciplines in Earth Observations. This will facilitate the association of the research cluster subdisciplines with the subsequent analysis of required supporting technology development items.

6.2.6.1. Requirements

Analysis of the 34 research clusters in Earth Observations has led to the identification of 82 STD requirements. These are distributed among the seven subdisciplines as well as two additional categories, the data gathering instrumentation specified by the research clusters and general systems that broadly affect the Earth Observations discipline. Table 6-21 presents the STD items identified in Earth Observations, together with their numerical identification. Note that the STD numbers are keyed to the Earth Observations discipline by an initial letter "E" and to their subdiscipline by an appropriate second letter. As with the research cluster numbering system described above, this facilitates the association of the STD items with their respective subdisciplines. The full documentation of the STD items can be found in Appendix E.

6.2.6.2. Data Summary

As the identification of STD items proceeded in the discipline of Earth Observations, it became evident that extensive commonality existed between the STD items and the research clusters to which they were applicable. This is shown

Table 6-20

EARTH OBSERVATIONS RESEARCH CLUSTERS (page 1 of 2)

Number	Research Cluster Title
	Agriculture/Forestry
6-A/F-1	Crop Inventory and Land Use
6-A/F-2	Soil Type Mapping
6-A/F-3	Crop Identification
6-A/F-4	Drop Vigor and Yield Prediction
6-A/F-5	Wildfire Detection and Mapping
	Earth Physics
6-EP-1	Photographic Coverage of the Earth
6-EP-2	Identification of Volcanic Activity
	Geography/Cartography
6-G/C-1	Photographic and Multisensor Mapping
	Geology
6-G-1	Rock and Soil Type Identification
6-G-2	Use of Earth's Crust to Store and Condition Commodities or Waste
6-G-3	Geologic Disaster Avoidance
6-G-4	Utilization of Geothermal Energy Sources
6-G-5	Mineral and Oil Deposit Discovery
6-G-6	Identification of Land Forms and Structural Forms
	Hydrology
6-H-1	Determination of Pollution in Water Resources
6-H-2	Flood Warning and Damage Assessment
6-H-3	Synoptic Inventory of Major Lakes and Reservoirs
6-H-4	Synoptic Inventory of Snow and Ice
6-H-5	Survey of Soil Moisture in Selected Areas of the North American Continent
6-H-6	Location of Underground Water Sources in Selected Areas
6-H-7	Survey of Hydrologic Features of Major River Basins

Table 6-20

EARTH OBSERVATIONS RESEARCH CLUSTERS (page 2 of 2)

Number	Research Cluster Title
	Meteorology
6-M-1	Determination of Boundary Layer Exchange Processes Using Infrared Radiometry
6-M-2	UHF Sferics Detection
6-M-3	Atmosphere Density Measurements by Stellar Occultation
6-M-4	Zero-G Environment Cloud Physics Experiment
6-M-5	Detection and Monitoring of Atmospheric Pollutants
6-M-6	Support of Studies of Special Geographical Areas
	Oceanography
6-O-1	Ocean Pollution Identification, Measurement, and Effects
6-O-2	Solar Energy Partition and Heating in the Sea Surface Layer
6-O-3	Ocean Population Dynamics and Fishery Resources
6-O-4	Ocean Currents and Tides Forecasting
6-O-5	Ocean Physical Properties
6-O-6	Ocean Solid Boundary Processes
6-O-7	Ocean Surface Activity Forecasting

in matrix form in Table 6-22; at each matrix intersection is the importance rating of each STD item relative to each applicable research cluster. A graphical presentation of this data in Figure 6-21 indicates 17 of the STD items impact on 50 percent of the research clusters in Earth Observations. This extensive commonality highlights the importance that timely supporting development will play in the success of the orbital Earth Observations program.

In Subsection 6.4.1, additional STD items that affect Earth Observations research clusters are presented. These items were derived from research clusters in other study disciplines, but are equally important to some research clusters in Earth Observations. Also presented in Subsection 6.4.1 are research clusters in other study disciplines affected by STD items derived

Table 6-21

EARTH OBSERVATIONS STD ITEMS (page 1 of 4)

STD Number	STD Title
	<u>Agriculture and Forestry</u>
EF-1	Vegetation Species Signature
EF-2	Soil Series Signature
EF-3	Crop Yield Signature
	<u>Earth Physics; Geography and Cartography; Geology</u>
EG-1	Quantification of Volcanic Morphology
EG-2	Multispectral Signature of Rocks
EG-3	Multispectral Signature of Rock and Soil Types
EG-4	Waste Flow Pattern Determination
EG-5	Multispectral Signature-Waste Storage Sites
EG-6	Laser Interferometer Relay System
EG-7	Multispectral Signature of Geothermal Sources
EG-8	Fourier Transform Analysis of Landforms
EG-9	Thermal Sensing of Seamounts
	<u>Hydrology</u>
EH-1	Water Pollution Identification Techniques
EH-2	Snow/Ice Depth Measurement Techniques
EH-3	Model of Snow/Ice Depth Signature
EH-4	Soil Moisture Measurement Techniques
	<u>Meteorology</u>
EM-1	Atmospheric Boundary Layer Model
EM-2	Atmospheric Effects by Surface Alterations
EM-3	Sferics Data Interpretation
EM-4	Stellar Scintillation Effects
EM-5	Atmospheric Density Applications
EM-6	Atmospheric Density by Dual Spacecraft
EM-7	Zero-G Cloud Physics Laboratory
EM-8	Aerosol Droplet Handling

Table 6-21 (page 2 of 4)

STD Number	STD Title
EM-9	Cloud Physics Experiment Priority
EM-10	Cloud Physics Lab-Related Uses
EM-11	Coherent Radiation - Pollution Detection
EM-12	Atmosphere Pollution Signature Analysis
EM-13	Atmosphere Model of Pollution Effects
EM-14	Tropical Cloud Systems Model
	<u>Oceanography</u>
EO-1	Ocean Pollution Identification Techniques
EO-2	Ocean Pollution Model
EO-3	Heat Flow Measurement Techniques
EO-4	Sea Surface Heating Model
EO-5	Chlorophyll Concentration Model
EO-6	Ocean Population Measurement Techniques
EO-7	Fish-Chlorophyll Correlation Model
EO-8	Radar Determination Sea Height
EO-9	Ocean Current/Height Model
EO-10	Ice Distribution Model
EO-11	Ocean Salinity Measurement Techniques
EO-12	Ocean Physical Properties Model
EO-13	Ocean Depth Model
EO-14	Boundary Processes Measurement Techniques
EO-15	Sea Surface Roughness Measurement Techniques
EO-16	Sea Surface Roughness Model
EO-17	Active/Passive Multispectral Radiometry
	<u>Instrumentation</u>
EI-1	Twin Metric Camera
EI-2	Multispectral Camera
EI-3	Ten-Band Multispectral Scanner
EI-4	Side-Looking Radar Imager

Table 6-21 (page 3 of 4)

STD Number	STD Title
EI-5	UV-Visible Absorption Spectrometer
EI-6	Multichannel Ocean Color Sensor
EI-7	Radar Altimeter/Scatterometer
EI-8	Microwave Scanner Radiometer
EI-9	UHF Sferic Detector
EI-10	Ground Station Data Collection System
EI-11	Star Tracking Telescope
EI-12	Zero-G Cloud Chamber
EI-13	Photoimaging Camera
EI-14	IR Interferometer Spectrometer
EI-15	Multispectral Tracking Telescope
EI-16	IR Selective Chopper Radiometer
EI-17	IR Filter Wedge Spectrometer
EI-18	IR Temperature Sounder
EI-19	Satellite IR Spectrometer
EI-20	Temperature Profile IR Radiometer
EI-21	Visible Wavelength Polarimeter
EI-22	UV Imager/Spectrometer
EI-23	Laser Altimeter
Systems	
ES-1	Ground Data Processing Center
ES-2	Automatic Data Transmission System
ES-3	Space Radiation Effects on Films
ES-4	Temperature-Humidity Effects on Films
ES-5	Photographic Film Storage Vault
ES-6	EVA-Instrument Maintenance
ES-7	EVA-Antenna Deployment
ES-8	Earth Obs. Crew Operations
ES-9	Photo-Processing System

Table 6-21 (page 4 of 4)

STD Number	STD Title
ES-10	Photo-Interpretation
ES-11	Spacecraft Effluent Effects
ES-12	Remote Data Degradation Effects

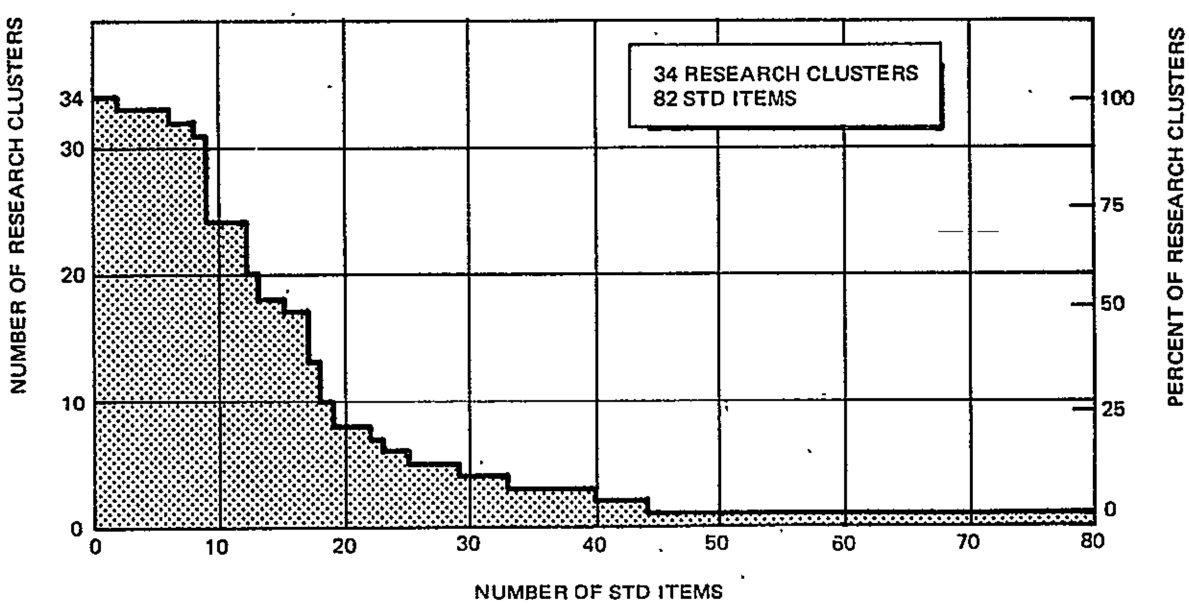

Figure 6-21. STD - Research Cluster Commonality Earth Observations.

TABLE 6-22. EARTH OBSERVATIONS COMMONALITY MATRIX.

STD NUMBER	STD TITLE	EARTH OBSERVATIONS RESEARCH CLUSTERS																																	
		6-A/F-1	6-A/F-2	6-A/F-3	6-A/F-4	6-A/F-5	6-EP-1	6-EP-2	6-G/C-1	6-G-1	6-G-2	6-G-3	6-G-4	6-G-5	6-G-6	6-H-1	6-H-2	6-H-3	6-H-4	6-H-5	6-H-6	6-H-7	6-M-1	6-M-2	6-M-3	6-M-4	6-M-5	6-M-6	6-O-1	6-O-2	6-O-3	6-O-4	6-O-5	6-O-6	6-O-7
	AGRICULTURE AND FORESTRY																																		
EF-1	VEGETATION SPECIES SIGNATURE	C		C																															
EF-2	SOIL SERIES SIGNATURE		C			I																													
EF-3	CROP YIELD SIGNATURE				I																														
	EARTH PHYSICS, GEOGRAPHY AND CARTOGRAPHY; GEOLOGY																																		
EG 1	QUANTIFICATION OF VOLCANIC MORPHOLOGY							C				I	I		C																				
EG-2	MULTISPECTRAL SIGNATURE OF ROCKS		C				C		C	C	C			C																					
EG-3	MULTISPECTRAL SIGNATURE OF ROCK AND SOIL TYPES		C				C	C	C	C	C	C	C	C	C					C	C	C													
EG-4	WASTE FLOW PATTERN DETERMINATION										I										C	I							I						
EG-5	MULTISPECTRAL SIGNATURE - WASTE STORAGE SITES										C										I														
EG-6	LASER INTERFEROMETER REI AY SYSTEM							I			I	C																							
EG-7	MULTISPECTRAL SIGNATURE OF GEOTHERMAL SOURCES							C					C	C																					
EG-8	FOURIER TRANSFORM ANALYSIS OF LANDFORMS													I	I																				
EG-9	THERMAL SENSING OF SEAMOUNTS														I																				
	HYDROLOGY																																		
EH 1	WATER POLLUTION IDENTIFICATION TECHNIQUES															C																			
EH 2	SNOW/ICE DEPTH MEASUREMENT TECHNIQUES																		I																
EH-3	MODEL OF SNOW/ICE DEPTH SIGNATURE																		I																
EH-4	SOIL MOISTURE MEASUREMENT TECHNIQUES																			C															
	METEOROLOGY																																		
EM 1	ATMOSPHERIC BOUNDARY LAYER MODEL																						C												
EM 2	ATMOSPHERIC EFFECT BY SURFACE ALTERATIONS																						I												
EM-3	SFERICS DATA INTERPRETATION																							I											
EM-4	STELLAR SCINTILLATION EFFECTS																								I										
EM-5	ATMOSPHERIC DENSITY APPLICATIONS																								I										
EM 6	ATMOSPHERIC DENSITY BY DUAL SPACECRAFT																								I										
EM 7	ZERO-G CLOUD PHYSICS LABORATORY																									C									
EM-8	AEROSOL DROPLET HANDLING																									I									
EM-9	CLOUD PHYSICS EXPERIMENT PRIORITY																									I									
EM 10	CLOUD PHYSICS LAB - RELATED USES																									I									
EM-11	COHERENT RADIATION - POLLUTION DETECTION																										I								
EM-12	ATMOSPHERIC POLLUTION SIGNATURE ANALYSIS																										C								
EM-13	ATMOSPHERIC MODEL OF POLLUTION EFFECTS																										C								
EM-14	TROPICAL CLOUD SYSTEMS MODEL																											C							
	OCEANOGRAPHY																																		
EO-1	OCEAN POLLUTION IDENTIFICATION TECHNIQUES																												C						
EO 2	OCEAN POLLUTION MODEL																												C						
EO-3	HEAT FLOW MEASUREMENT TECHNIQUES																													C					
EO-4	SEA SURFACE HEATING MODEL																													I					
EO-5	CHLOROPHYLL CONCENTRATION MODEL																														I				
EO-6	OCEAN POPULATION MEASUREMENT TECHNIQUES																														C				
EO 7	FISH - CHLOROPHYLL CORRELATION MODEL																														I				
EO-8	RADAR DETERMINATION SEA HEIGHT																															I			
EO 9	OCEAN CURRENT/HEIGHT MODEL																															C			
EO 10	ICE DISTRIBUTION MODEL																																I		
EO 11	OCEAN SALINITY MEASUREMENT TECHNIQUES																																I		
EO-12	OCEAN PHYSICAL PROPERTIES MODEL																																C		
EO-13	OCEAN DEPTH MODEL																																	C	
EO 14	BOUNDARY PROCESSES MEASUREMENT TECHNIQUES																																	I	
EO-15	SEA SURFACE ROUGHNESS MEASURE TECHNIQUES																																		C
EO-16	SEA SURFACE ROUGHNESS MODEL																																		I
EO-17	ACTIVE/PASSIVE MULTISPECTRAL RADIOMETRY																												I	I	I		I		I
	INSTRUMENTATION																																		
EI-1	TWIN METRIC CAMERA	C	C	C	C	C	C	I	C	C	C	C	I	C	C	C	C	C	C	C	C	C	I	I			I	C	I	I	I	I	I	C	I
EI-2	MULTISPECTRAL CAMERA	C	C	C	C	C	C	I	C	C	C	C	I	C	C	C		I				I												C	
EI-3	TEN-BAND MULTISPECTRAL SCANNER	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C		I	I	C	C	I							C	C	C			I	
EI-4	SIDE-LOOKING RADAR IMAGER	C	C	C	C			I		I	I	C	I	C	I		C	C	C			C										I	C		
EI-5	UV-VISIBLE ABSORPTION SPECTROMETER													I													C		I						
EI-6	MULTICHANNEL OCEAN COLOR SENSOR	I	I	I	I											C													C	C	C				
EI 7	RADAR ALTIMETER/SCATTEROMETER	I																												C		C		I	C
EI-8	MICROWAVE SCANNER RADIOMETER	I		C		C				C	C	C		C	C		C		I	C									C	C	C		C		C
EI-9	UHF SFERIC DETECTOR					C																		C				C							
EI 10	GROUND STATION DATA COLLECTION SYSTEM		C		C	C						C				C	C	I	I	I	C	I							C	C	C	C	C	C	C
EI-11	STAR TRACKING TELESCOPE																								C										
EI-12	ZERO-G CLOUD CHAMBER																									C									
EI-13	PHOTO IMAGING CAMERA	I	I	I	I	C						C					C																		
EI 14	IR INTERFEROMETER SPECTROMETER	I	C	C	C	I				C	C												C					C							
EI 15	MULTISPECTRAL TRACKING TELESCOPE	C	C	I	I	C																													
EI 16	IR SELECTIVE CHOPPER RADIOMETER	C			C	I																	C					C							
EI-17	IR FILTER WEDGE SPECTROMETER	C		C	C	C																	C					C							
EI-18	IR TEMPERATURE SOUNDER					I																	C					C							
EI-19	SATELLITE IR SPECTROMETER	I	C																				C					C							
EI 20	TEMPERATURE PROFILE IR RADIOMETER					I																	C					C							
EI 21	VISIBLE WAVELENGTH POLARIMETER	C		C	C																														
EI 22	UV IMAGER/SPECTROMETER	C	C	C	C																														
EI 23	LASER ALTIMETER						I					C	I	C	I		C					C										I			
	SYSTEMS																																		
ES-1	GROUND DATA PROCESSING CENTER	I	I	C	C	C	I	I	I	I	I	C	I	I	I	C	C	I	C	C	I	I	I	I	I	I	C	I	C	I	I	I	I	I	C
ES-2	AUTOMATIC DATA TRANSMISSION SYSTEM					I						I				I	I										I		I			I			I
ES 3	SPACE RADIATION EFFECTS ON FILMS	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I		I	I	I	I	I	I	I	I	I	I
ES-4	TEMPERATURE-HUMIDITY EFFECTS ON FILMS	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I		I	I	I	I	I	I	I	I	I	I
ES-5	PHOTOGRAPHIC FILM STORAGE VAULT	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C		C	C	C	C	C	C	C	C	C	C
ES-6	EVA INSTRUMENT MAINTENANCE	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I		I	I	I	I	I	I	I	I	I
ES-7	EVA-ANTENNA DEPLOYMENT	I	I	I	I			I		I	I	I	I	I	I		I	I	I			I								I		I	I	I	I
ES-8	EARTH OBSERVATION CREW OPERATIONS	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
ES-9	PHOTO-PROCESSING SYSTEM	I	I	I	I	I			I	I	I	C	I	I	I	I	C	I	C	I	I	I				C	C		C		I			I	
ES 10	PHOTO-INTERPRETATION SYSTEM	I	I	I	I	I			I	I	I	C	I	I	I	I	C	I	C	I	I	I				C	C		C		I			I	
ES-11	SPACECRAFT EFFLUENT EFFECTS	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I		I	I	I	I	I	I	I	I	I
ES-12	REMOTE DATA DEGRADATION EFFECTS	I	I	I	I	I	I	I	I	I		I	I	I	I	I	I	I	I	I	I	I	I				I	I	I	I	I	I	I	I	I

C - CRITICAL, I - IMPORTANT

in Earth Observations. This data on multidiscipline STD items are an important factor in organizing an integrated program of supporting technology development.

Figure 6-22 presents the distribution of STD activities in the discipline of Earth Observations. Note that there is a relatively even distribution across the study, nonspace experiment, and development categories. Due to the relatively tender age of remote sensing, as applied to the terrestrial sciences, extensive theoretical modeling is required to relate sensor parameters, such as spectral range and resolution, spatial resolution, and aspect angle of both source and return radiation, to measurement requirements, such as plant vigor, Geological formations, and pollution. To support and verify these theoretical models, nonspace experiments (especially by aircraft) are necessary These experiments also apply to the development of the sensing instrumentation required to fulfill the measurement requirements. This accounts for the emphasis placed on studies, nonspace experiments, and development in Earth Observations. This rationale is verified by the distribution of STD objectives presented in Figure 6-23. The relatively high percentage of theory and systems reflects the modeling studies and systems experimentation and development described above.

Figures 6-24 and 6-25 present the distributions of the estimated time and cost requirements of the STD items in the Earth Observations discipline. These data indicate that almost 65 percent of the STD items require one to two years for completion and about 50 percent of the items cost $100,000 to $500,000.

6.2.6.3. Conclusions

In the course of the identification of STD requirements in Earth Observations, certain technologies that are particularly far-reaching in impact became apparent. These can be inferred from Table 6-23 which presents the STD items affecting the largest number of research clusters in Earth Observations. The item that heads this listing is the requirements for a ground data processing center. Expanding on this, the general problem of processing the

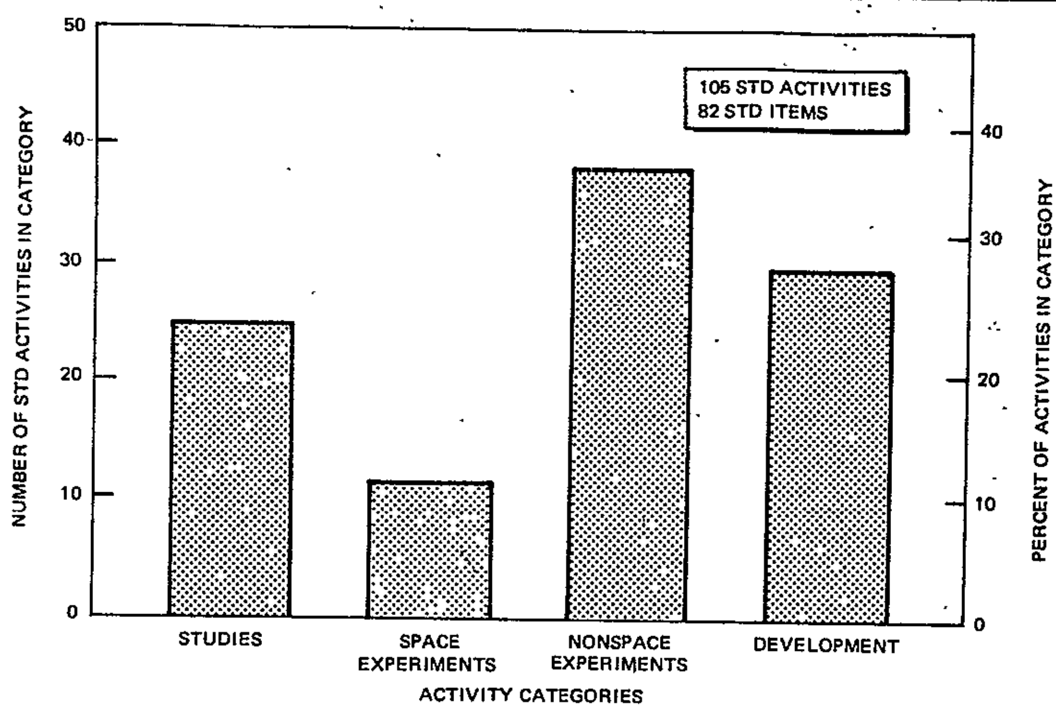

Figure 6-22. Earth Observations - STD Activities Distribution.

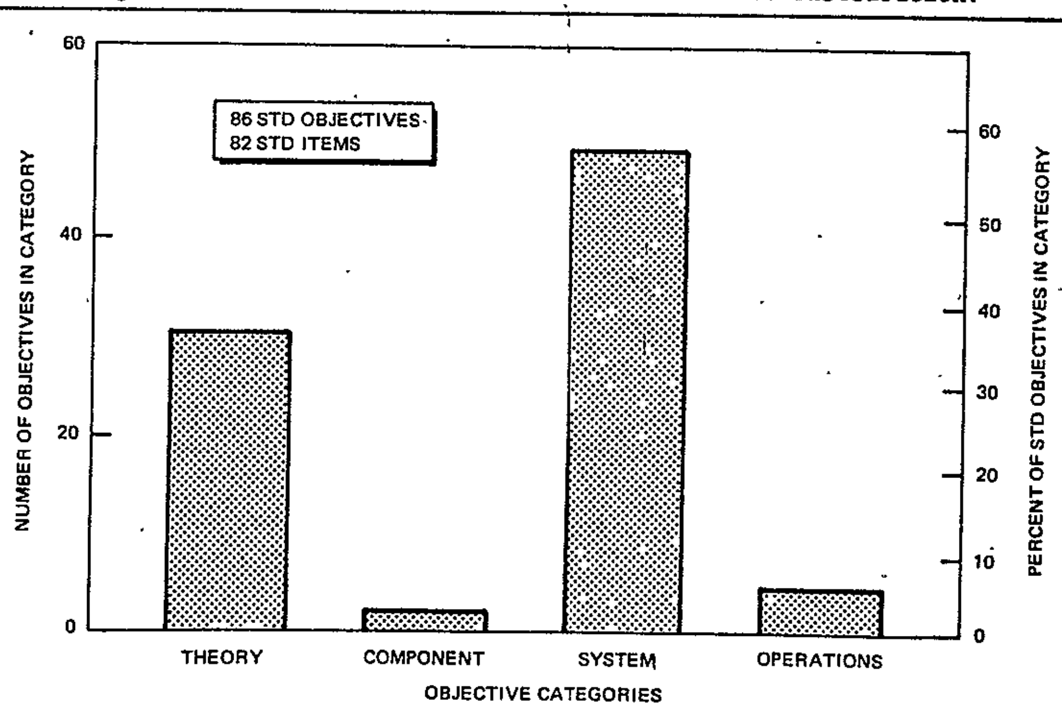

Figure 6-23. Earth Observations - STD Objectives Distribution.

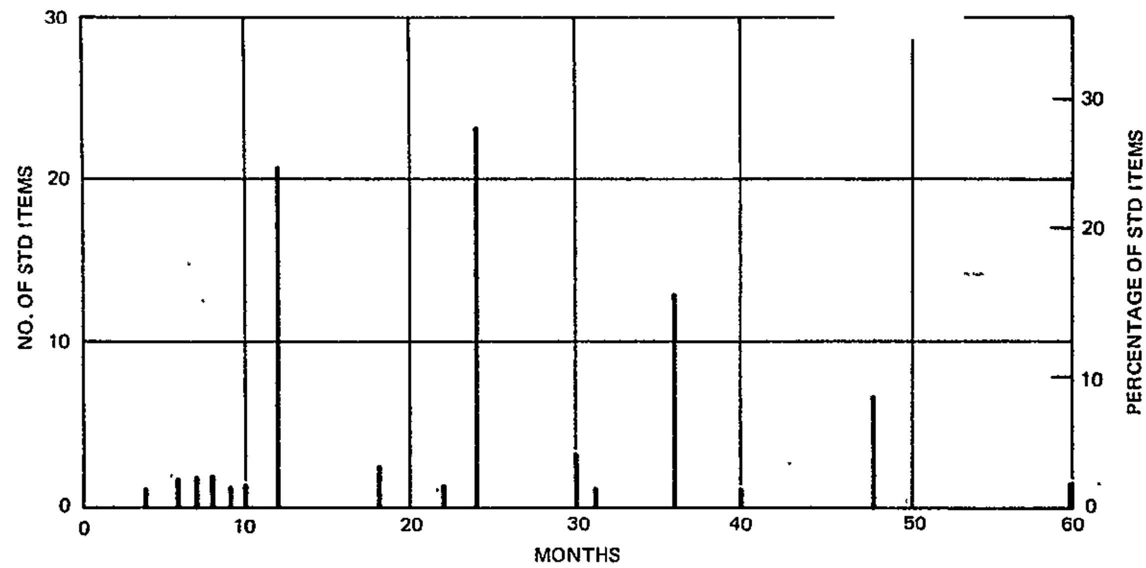

Figure 6-24. STD Time Estimates for Earth Observations (82 STD Items).

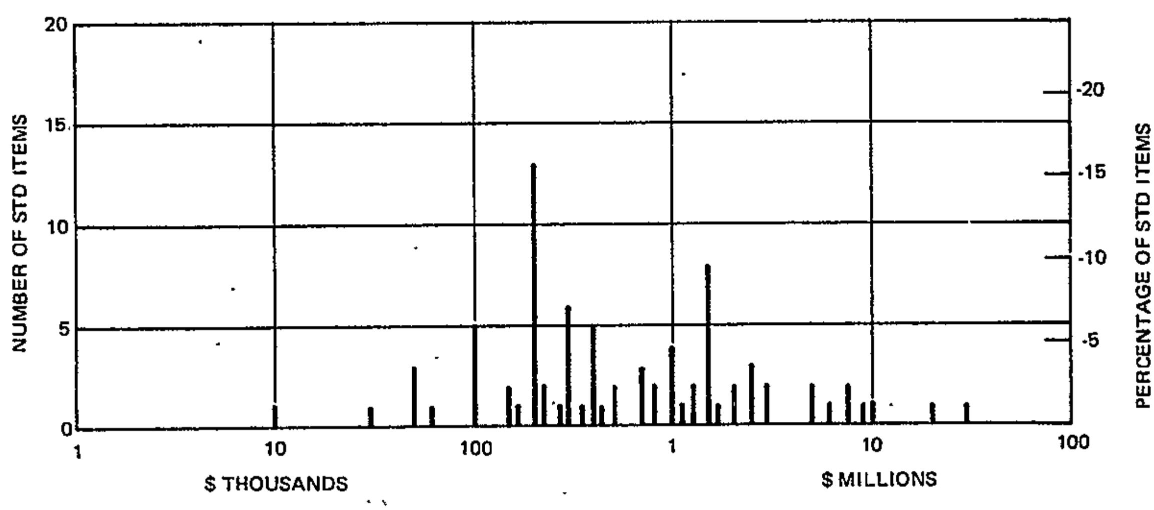

Figure 6-25. Cost Estimates for Earth Observations (82 STD Items).

wealth of data obtainable by an orbital observations system and disseminating this information to the user agencies in a usable form within time constraints is probably the single most intricate problem to be met before an operational system is attained. Included in this problem is the degree of data processing to be done in orbit and communicated directly to user receiving systems, as is done in the Automatic Picture Transmission (APT) system currently used in meteorological satellites. The complexity of dealing with private enterprise, and national and international agencies, also is involved if orbital Earth Observations are to ever realize their full potential in improving the human environment.

Related to the question of data processing onboard the spacecraft is the relatively undefined role of man in support of an orbital Earth Observations program. The degree to which man can efficiently participate in the selection of observation, targets, scheduling, sensor deployment and operation, and data processing, interpretation and dissemination remains to be fully defined. This information is necessary to identify the requirements for crew skills, detailed instrument design and support equipment, and the effects on nonrelated experiments and operations.

Another technology affecting almost all of Earth Observations is that of photographic systems. The effects of the spacecraft environment on photographic film is poorly defined, particularly the effects of natural space radiation. Currently available data on radiation effects as well as the effects of storage temperature and humidity have not been put in terms of image interpretability and information return to the experimenter, hence the requirements for orbital handling and storage of films are poorly defined. The capability to process in orbit most of the special purpose color and infrared films used in Earth Observations is also nonexistent. Also unavailable is the equipment necessary to evaluate photographic imagery by crewmen in orbit. The highly integrated nature of photographic systems to the success of the Earth Observations experiment program highlights the importance of increased emphasis on upgrading this technology for orbital applications.

Table 6-23

EARTH OBSERVATIONS STD-RESEARCH CLUSTER COMMONALITY

STD No.	Candidate STD Requirement	% Research Clusters Critical	Important	Total
ES-1	Ground Data Processing Center	32	68	100
ES-8	Crew Operations Definition		100	100
ES-3	Space Radiation Effects on Films		97	97
ES-4	Temperature Humidity Effects on Films		97	97
ES-5	Photographic Film Storage Vault	97		97
ES-6	EVA-Instrument Maintenance		97	97
ES-11	Spacecraft Effluent Effects		97	97
EI-1	Twin Metric Camera	62	32	94
ES-12	Remote Data Degradation Effects		91	91
ES-9,10	Photographic Film Processor/ Evaluation	18	54	72
EI-3	Ten-Band Multispectral Scanner	59	12	71
ES-7	EVA-Contingency Antenna Deployment		59	59
EI-2	Multispectral Camera	41	12	53
EI-10	Ground Station Data Collection System	41	12	53

Spacecraft effluent effects are another major area of impact on the success of the orbital Earth Observations Program. The cloud of particulate debris and gases emitted by spacecraft cabin leakage, waste dumps and thrustor operations as well as the electromagnetic interference caused by spacecraft equipment and thrustor firings can severely degrade the desired measurement quality. Effluents and interferences by the experiment equipment, both within and outside the Earth Observations discipline, must also be considered. Our present knowledge of the spatial extent, dynamic characteristics, and physical constituents of the spacecraft effluent cloud is relatively poor. The effects on data quality, especially spatial resolution and spectral energy distribution, have also not been evaluated. An assessment of the spacecraft effluent problem is a necessary precursor to detailed spacecraft designs and operations plans.

Finally, the general requirement exists for more nonspace ground truth measurements across all the subdisciplines in Earth Observations. The correlation of measurement parameters with measurement objectives is as yet incomplete. Ground resolution requirements are particularly critical for measurements from orbit and these can be estimated only at present. Hence, the instrument angular resolution specifications which figure so critically in development cost are not reliable. To a lesser degree, the same situation exists in spectral bandwidth requirements. The multiplicity of uses for which Earth Observations data can be applied adds to the complexity of this problem as well as to its importance. Further aircraft flight testing over ground truth sites is necessary to evaluate instrument performance and data correlation with measurement objectives. This will pinpoint the instrument specifications required and perhaps even lead to a more selective criteria for designating those measurements to be performed from orbit.

6.3. STD DATA SUMMARY

A complete summary of data from the STD requirement descriptions is presented in Table 6-24. The table is arranged according to discipline and subdiscipline, and lists the number and name of each of the 238 identified STD items. Also included for each STD item are criticality, activities, objectives, confidence level, range of achievement time estimates, and range of cost estimates. These data are further summarized in Figures 6-26 through 6-30.

Of the 371 STD activities identified, approximately 32 percent are studies, 9 percent are experiments in space, 22 percent are experiments not in space, and 38 percent are developments. This is illustrated by the bar chart in Figure 6-26, which includes further detail with respect to the research cluster disciplines.

C-9

The 238 STD items identify 309 objectives. About 48 percent of the objectives are for systems, and slightly more than 15 percent are in each of the other three objective categories - theory, components, and operations. These percentages are shown on the bar chart (Figure 6-27) with details for each discipline.

The time estimates for accomplishing the STD activities are summarized in Figure 6-28. This figure shows the time estimates to be predominantly for one, two, and three years. Only 12 time estimates are for five years or more, and three estimates are at the maximum of ten years.

The minimum and maximum cost estimates are summarized in Figures 6-29 and 6-30. Note that the abscissas for these figures are logarithmic scales. Most STD items do not have a cost range, so the two figures are almost the same; however, there is a significant shift at the high end of the scale, particularly for two Space Astronomy experiments. The order-of-magnitude shift for these two experiments is due to allowances made for commonality in the items (see Subsection 6.2.3).

6.4. STD PROGRAM SYNTHESIS

Whereas the discussion up to this point has focused on individual STD items, it is now concerned with groups of STD items so structured as to form logical work packages. When these work packages have been formed, the programs necessary for meeting the STD requirements may be synthesized. Thus, while previous subsections have stated what should be done, the following material offers thoughts on how these things could be done.

This subsection begins with a treatment of experiment commonality (6.4.1) which assesses the importance rating (critical or important) of each STD item with respect to every research cluster. This out-of-discipline commonality supplements the commonality previously derived for each study discipline in Subsections 6.2.1. through 6.2.6. Next, the formation of the STD groups is described in Subsection 6.4.2. Here the aim is to collect the STD items into groups that should be studied, developed, or experimented upon together because of dominant interrelationships.

TABLE 6-24. (page 1 of 7)

SUPPORTING TECHNOLOGY DEVELOPMENT DATA SUMMARY

STD NO	STD TITLE	CRITICALITY	ACTIVITIES	OBJECTIVES	CONFIDENCE	TIME ESTIMATES (MONTHS)	COST ESTIMATES (THOUSAND DOLLARS)
	MANNED SPACEFLIGHT CAPABILITY – BIOMEDICINE						
BM-1	BODY FLUID ANALYSIS	I	S	S,O	H	24	200
BM-2	NON-INVASIVE CENTRAL VENOUS PRESSURE MEASUREMENT	I	S	T,C	L	24	100
BM-3	ANIMAL TOXIOCOLOGICAL CHAMBER	C	D	S	H	24	1500
BM-4	MANNED ORBITAL ANIMAL RESEARCH FACILITY	C	D	S	H	36	5000
BM-5	RADIATION SOURCE	C	S	S	H	12	100
BM-6	SPACE THERMAL ENCLOSURE	C	NE	C	H	12	300
BM-7	SENSITIVE QUANTITATIVE EVALUATION OF REFLEX FUNCTIONS	I	NE	O	H	12	150
BM-8	ENDORADIOSONDE	I	NE	O	H	12	200
BM-9	ANIMAL SENSORS	C	S,D	C	H	24	1000
BM-10	ANIMAL MODULES	C	D	S	H	36	5000
BM-11	BODY VOLUMETER	C	D	T,S	M	12	750
BM-12	MEASUREMENT OF TRANSPULMANORY PRESSURE	I	D	C	H	24	100
	MANNED SPACEFLIGHT CAPABILITY – BEHAVIORAL RESEARCH						
BR-1	HEARING	I	NE	T,O	H	12	100
BR-2	AUDIO TONE SOURCE	I	D	C	H	12	100
BR-3	PSYCHOMOTOR TESTS IN SIMULATED ZERO-G	I	NE	O	H	12	300
BR-4	COGNITIVE MEASUREMENTS TEST MODULE	I	D	S	H	36	600
BR-5	AUTOMATED BEHAVIOR DATA FROM VIDEO AND AUDIO RECORDS	I	S,NE,D	O	H	36	750
BR-6	VERBAL BEHAVIOR ASSESSMENT PROGRAM	C	NE,D	T,O	H	24	750
BR-7	HAZARDOUS COMPLEX TASKS	I	S,NE	O	H	24	200
BR-8	TRAINING PROBLEMS AND EQUIPMENT	I	S,NE,D	C,O	H	24	1000
	MANNED SPACEFLIGHT CAPABILITY – MAN-MACHINE RESEARCH						
MM-1	DISPLAY/CONTROL COMPUTER CAPABILITY	C	D	S	H	36	1500
MM-2	DISPLAY/CONTROL EXPERIMENTAL APPARATUS	C	D	C	H	24	1000
MM-3	DARK ADAPTION EQUIPMENT AND TECHNIQUES	I	SE,NE	O	H	18	100
MM-4	PORTABLE METABOLIC ANALYZER	C	D	C	H	36	1500
MM-5	ONBODY ACCELEROMETER	C	D	S	H	36	400
MM-6	HABITABILITY EXPERIMENT SUPPORT PACKAGE	C	NE,D	S	H	36	1000
MM-7	EMERGENCY REACTION TIME FROM SLEEP	C	NE	O	H	24	200
MM-8	EQUIPMENT FOR SLEEP EXPERIMENTS	C	D	C	H	12	100
MM-9	PERFORMANCE AIDS	C	NE,D	S,O	H	60	5000

CRITICALITY: C – CRITICAL; I – IMPORTANT

ACTIVITIES: S – STUDY; SE – EXPERIMENT IN SPACE; NE – EXPERIMENT NOT IN SPACE; D – DEVELOPMENT

OBJECTIVES: T – THEORY; C – COMPONENT; S – SYSTEM; O – OPERATIONS

CONFIDENCE: H – HIGH; M – MEDIUM; L – LOW

TABLE 6-24 (page 2 of 7)

SUPPORTING TECHNOLOGY DEVELOPMENT DATA SUMMARY

STD NO.	STD TITLE	CRITICALITY	ACTIVITIES	OBJECTIVES	CONFIDENCE	TIME ESTIMATES (MONTHS)	COST ESTIMATES (THOUSAND DOLLARS)
	MANNED SPACEFLIGHT CAPABILITY – LIFE SUPPORT AND PROTECTIVE SYSTEMS						
LS-1	MULTIPURPOSE FLUID PHYSICS APPARATUS	C	S,D	S	H	24	1000
LS-2	ZERO-G CONDENSER	C	SE,NE,D	S,O	H	36	600
LS-3	CATALYST BED POISONS	I	D	C	H	12	250
LS-4	NEGATIVE PRESSURE DEVICE	I	NE,D	C	H	12	700
LS-5	ZERO-G PHASE SEPARATOR	C	SE, NE, D	C,S	H	24	400
LS-6	AUTOMATIC POTABILITY MEASURE	C	S,D	T,S	H	60	5000
LS-7	LOW-FLOW METERING DEVICE	I	D	C	H	24	500
LS-8	SEPARATION OF EFFLUENT GASES FROM ELECTROLYTE	C	NE,D	S,O	H	30	750
LS-9	IDENTIFICATION OF CONTAMINANTS IN ELECTROLYSIS PRODUCTS	C	S,NE,D	S	H	24	500
LS-10	EVALUATION OF HYDROGENOMONAS EUTROPHA REACTION CHAMBER	C	D	S	H	12	600
LS-11	INTEGRATION OF HYDROGENOMONAS EUTROPHA SYSTEM COMPONENTS	C	D	S	H	24	200
LS-12	DEVELOPMENT OF CO_2 REMOVAL METHODS	C	D	T,S	H	24	800
LS-13	BOILING AND CONDENSING STEAM	C	NE,D	S,O	H	24	675
LS-14	WASTE MANAGEMENT SYSTEMS	C	D	S	H	24	800
LS-15	MICROBIAL DETECTION AND SUPPRESSION	C	S, NE, D	T,S	H	60 – 120	10000
LS-16	SYSTEMS INTEGRATION OF SENSORS	I	D	S	H	24	1500
LS-17	WASTE MANAGEMENT SYSTEM CONCEPTS	I	S	T,C,S	H	12	500
	MANNED SPACEFLIGHT CAPABILITY – ENGINEERING EXPERIMENTS						
EE-1	BIOWASTE ELECTRICAL PROPULSION	C	S,NE,D	S	H	36	2000
EE-2	BIOWASTE RESISTOJETS	C	S,NE,D	C	H	21	400
EE-3	BIOWASTE RESISTOJET EVA	C	S,NE	O	H	0 – 12	0 – 200
EE-4	LASER RANGING SYSTEM	C	S,D	S	H	36	3000
EE-5	LANDMARK TRACKER SYSTEM	C	S,D	S	H	18 – 24	3000
EE-6	LONG-RANGE OPTICAL COMMUNICATIONS	C	S,D	S	H	36	10000
	MANNED SPACEFLIGHT CAPABILITY – OPERATIONS EXPERIMENTS						
OE-1	ASSEMBLY TECHNIQUES STUDY	C	S,NE	O	H	18	500

TABLE 6-24 (page 3 of 7)

SUPPORTING TECHNOLOGY DEVELOPMENT DATA SUMMARY

STD NO.	STD TITLE	CRITICALITY	ACTIVITIES	OBJECTIVES	CONFIDENCE	TIME ESTIMATES (MONTHS)	COST ESTIMATES (THOUSAND DOLLARS)
	SPACE BIOLOGY						
B-1	AMINO ACID ANALYZER	C	S,SE,D	C,O	H	48	2100
B-2	-180°C TISSUE FREEZER	C	D	S,O	H	12 – 24	100 – 500
B-3	ZERO-G ANIMAL CAGES	C	D	S,O	H	12 – 24	75 – 100
B-4	ANIMAL BIOCENTRIFUGE	C	D	S	M	60	10000 – 15000
B-5	SURGICAL PROCEDURES	C	S,SE	O	H	12	500
B-6	ZERO-G AUTOCLAVE	C	D	C	H	12	200
B-7	ZERO-G INCUBATOR	C	D	C	H	12	200
B-8	TISSUE PROCESSOR	I	D	S	H	12 – 24	50
B-9	ACTIVITY PLATFORM	I	S,D	O	H	12 – 24	100
B-10	VISUAL CLIFF	I	S	O	H	12 – 24	50
B-11	ANIMAL MAZE	I	S,D	O	H	36	550
B-12	BUNSEN BURNER SUBSTITUTE	I	S	C,O	H	6	50
B-13	LIQUID HANDLING	C	S,SE,NE	O	H	24 – 36	1000
B-14	AUTOMATED MICROBIAL IDENTIFICATION	I	D	S,O	H	60	300
B-15	ZERO-G HOMOGENIZER	C	D	C	H	12	50
B-16	DIALYSIS EQUIPMENT	C	D	C	H	12	50
B-17	BLOOD CELL COUNTER	I	D	S	H	12 – 24	100
B-18	FLUID ELECTROLYTE ANALYZER	C	D	S	H	12 – 24	500 – 1000
B-19	ADVANCED PLETHYSMOGRAPH	I	D	C	H	6 – 12	25
B-20	SMALL PARTICLE MASS MEASUREMENT	C	S,SE,NE,D	S,O	M	36 – 60	1000
B-21	EQUIPMENT ANALYSIS AND INTEGRATION	I	S	S,O	H	12 – 24	5000 – 10000
	SPACE ASTRONOMY						
A-1	HIGH-RESOLUTION OPTICAL SYSTEMS	C	S,SE,NE,D	T,C,S,O	L	120	5000 – 500000
A-2	ELECTRONIC IMAGE INTENSIFIERS	C	S,D	C	M	12	200
A-3	TELESCOPE OPERATION IN SPACE	C	S,NE	S,O	M	12 – 24	250 – 750
A-4	ORBIT-TO-ORBIT SHUTTLE REQUIREMENTS	I	S	S	H	12	300
A-5	ASSEMBLY AND ALIGNMENT OF HIGH-RESOLUTION TELESCOPE IN SPACE	C	S,SE,NE	S,O	L	38	6500
A-6	DEVELOPMENTS FOR USE OF HIGH-RESOLUTION TELESCOPE	C	S,NE	S,O	M	12 – 18	250 – 750
A-7	DEVELOPMENT OF USE OF PHOTOGRAPHIC FILM FOR SPACE ASTRONOMY	C	S,SE,D	C,S,O	M	23	690
A-8	HIGH-RESOLUTION OPTICAL TELESCOPES	C	S,SE,NE,D	T,C,S,O	L	120	50000 – 500000
A-9	ELECTRONIC IMAGE INTENSIFIERS	I	S,D	C	M	9	100
A-10	ACQUISITION OF CELESTIAL TARGETS	C	S,NE,D	C,S,O	M	24	700
A-11	HIGH-PRECISION STELLAR PHOTOMETRY	C	S,NE,D	C,S,O	M	18 – 36	400
A-12	COOLING OF SOLAR ASTRONOMY TELESCOPES	C	S,NE,D	C,S	M	30	575
A-13	ACQUISITION AND TRACKING OF SOLAR TARGETS	C	S,SE,NE,D	T,C,S,O	M	39	600

TABLE 6-24 (page 4 of 7)

SUPPORTING TECHNOLOGY DEVELOPMENT DATA SUMMARY

STD NO.	STD TITLE	CRITICALITY	ACTIVITIES	OBJECTIVES	CONFIDENCE	TIME ESTIMATES (MONTHS)	COST ESTIMATE (THOUSAND DOLLARS)
	SPACE PHYSICS						
P-1	MASS SPECTROMETER	I	S	C	H	12	500
P-2	GAS CHROMATOGRAPH	I	S	C	H	12	500
P-3	PYROMETER	C	D	S	H	12	200
P-4	APPARATUS FOR LIQUID/VAPOR STUDIES	C	S,D	S	H	24	1100
P-5	LOW-G ACCELEROMETER	C	S,SE	C	H	24	700
P-6	LOW-G ISOLATION MOUNTS	C	S,SE,NE	C	H	12	200
P-7	CRYSTAL GROWING APPARATUS	C	S,D	S	H	18	700
P-8	ZONE REFINING APPARATUS	C	S	S	H	6	500
P-9	PRODUCTION OF HARD VACUUMS	C	S,SE	T,S	H	24	750
P-10	CONTAMINATION BY PHYSICS APPARATUS	I	S,NE	S,O	H	18	1000
P-11	MELTING APPARATUS	C	S,D	S	H	24	1250
P-12	SAMPLE CENTERING DEVICE	I	S	S	H	6	200
P-13	FILM DRAWING EXPERIMENTS	C	SE	S,O	H	18	1500
P-14	OPTIMUM MATERIAL HEATING	I	S	C,S,O	H	9	500
P-15	COSMIC RAY EXPERIMENT PACKAGE	C	S,D	S	H	33	10250
P-16	LASER HOLOGRAPHY	I	S	S	H	12	500
P-17	CONTAMINANT-PROOF EC&LS SYSTEM	C	S,NE,D	C,S	M	48	10000
P-18	HEAT TRANSFER CHAMBER	C	D	S	H	12	500
P-19	SUPERCONDUCTING MAGNETS	I	S	C	H	12	500
P-20	INTEGRATED PHYSICS APPARATUS	I	S	S,O	H	18	750
P-21	WICKING APPARATUS	C	D	S	H	12	1000
P-22	G-LEVEL CONTROL	C	S,D	S	M	30	1100
P-23	HEAT TRANSFER APPARATUS	C	D	S,O	H	24	2000
P-24	APPARATUS FOR CONTROLLED DENSITY MATERIAL STUDY	C	S,D	S	H	30	2100
P-25	FILM-VIDEO TAPE TRADE STUDY	I	S	S,O	H	12	200
P-26	ONBOARD FILM PROCESSING	I	D	S	M	24	5000
P-27	TRANSITION RADIATION DETECTOR	I	S,NE,D	T,C,S	M	36	2000
P-28	SUPERCONDUCTING MATERIALS	I	S,NE	T,C	M	36	3000
P-29	CRYOGENIC SYSTEMS	C	S,SE,NE	S,O	H	24	1500
P-30	PLASMA PHYSICS SUBSATELLITES	C	S,D	S,O	H	48	10100
P-31	DC ELECTRIC FIELD MEASUREMENTS	I	S,NE,D	T,C	M	36	2000
P-32	PLASMA DIAGNOSTICS TECHNIQUES	I	S	T,O	H	9	200
P-33	BARIUM CLOUD APPARATUS	C	D	C,S	H	30	10000
P-34	INTENSE ELECTRON SOURCES	I	S,SE,D	S	H	24	5500
P-35	RESEARCH IN PLASMA PHYSICS	C	S,SE	T	H	60	5000
P-36	APPARATUS FOR SUPERFLUIDITY TESTS	C	S,D	S	H	36	2500
P-37	DEWAR VIEWPORT STUDIES	C	S,D	C	H	9	300
P-38	CRYOGENIC REMOTE HANDLING	C	S,NE	C	H	12	500
P-39	SUPERFLUID RESEARCH	C	S	T	H	36	1500

TABLE 6-24 (page 5 of 7)

SUPPORTING TECHNOLOGY DEVELOPMENT DATA SUMMARY

STD NO.	STD TITLE	CRITICALITY	ACTIVITIES	OBJECTIVES	CONFIDENCE	TIME ESTIMATES (MONTHS)	COST ESTIMATE (THOUSAND DOLLARS)
	COMMUNICATIONS AND NAVIGATION						
C-1	94 GHz AMPLITUDE AND PHASE MEASUREMENT SYSTEM	C	D	S	M	36	5000
C-2	MM WAVES EXPERIMENT PLAN	C	S	S,O	H	12	250
C-3	MM WAVES EXPERIMENT PACKAGE	C	D	S	H	24	5000
C-4	BROADBAND MODULATORS	C	S,D	C,S	H	33	5200
C-5	HIGH SPEED CORRELATOR	I	S,D	S	H	24	800
C-6	LASER TELESCOPE ALIGNMENT	I	S,SE,D	C,S	H	84	10000
C-7	IMPROVED SATELLITE TRACKING	I	S,D	S	M	36	2500
C-8	SUBSATELLITE FOR NAVIGATION	C	D	S	H	36	10000
C-9	TRANSPONDERS FOR NAVIGATION SATELLITES	I	D	C,S	H	24	3000
C-10	DATA PROCESSING SOFTWARE	C	S,D	S	H	36	1000
C-11	SATELLITE POSITION DETERMINATION	I	S	S	H	12	250
C-12	LASER RADAR DEVELOPMENT	C	D	S	H	24	2000
C-13	AUTONOMOUS NAVIGATION SENSORS	C	D	S	H	36	4000
C-14	IMPROVED POSITION DETERMINATION	I	S,D	S	H	36	2500
C-15	SOFTWARE DEVELOPMENT FOR AUTONOMOUS NAVIGATION	C	S,D	T	M	24	2250
C-16	SUBSATELLITES FOR SURVEILLANCE	C	D	S	H	36	10000
C-17	TRANSPONDERS FOR SURVEILLANCE SYSTEMS	I	D	C	H	24	3000
C-18	DATA PROCESSING SOFTWARE	I	S,D	S	M	36	1250
C-19	COLLISION AVOIDANCE HARDWARE	C	S,D	C,S	H	27	1200
C-20	EMERGENCY LOCATION SIGNAL DETECTORS	I	D	C	H	12	1000
C-21	SOFTWARE DEVELOPMENT FOR LOCATION METHODS	I	S,D	T	H	24	1000
C-22	LOW NOISE RECEIVERS	C	S,D	C	M	39	5500
C-23	COMPUTER SOFTWARE FOR NOISE MEASUREMENTS	I	S,D	S	H	36	1500
C-24	NOISE SOURCE IDENTIFICATION PLAN	C	S	S,O	H	12	250
C-25	DIGITAL IONOSOUNDER	I	D	C	H	12	2000
C-26	HIGHER EFFICIENCY RF TRANSMITTERS	I	S,D	C	H	45	5250
C-27	HIGH POWER RF TRANSMITTERS	C	D	C	M	24	2000
C-28	COMPUTER SOFTWARE FOR PROPAGATION EXPERIMENTS	I	S,D	S	H	18	400
C-29	SELF-STEERING PHASED ARRAY ANTENNA	I	S,NE,D	C,S	H	36	1250
C-30	OPTICAL COMMUNICATIONS SYSTEM	C	S,D	C,S	H	48	11000
	EARTH OBSERVATIONS – AGRICULTURE AND FORESTRY						
EF-1	VEGETATION SPECIES SIGNATURE	C	SE, NE	T	H	36	1500
EF-2	SOIL SERIES SIGNATURE	C	SE, NE	T	M	36	1500
EF-3	CROP YIELD SIGNATURE	I	SE, NE	T	H	36	1500
	EARTH OBSERVATIONS – EARTH PHYSICS; GEOGRAPHY AND CARTOGRAPHY; GEOLOGY						
EG-1	QUANTIFICATION OF VOLCANIC MORPHOLOGY	C	NE	T	H	12	350
EG-2	MULTISPECTRAL SIGNATURE OF ROCKS	C	NE	T,S	H	12	1300
EG-3	MULTISPECTRAL SIGNATURE OF ROCK AND SOIL TYPES	C	NE	T,S	H	12	200
EG-4	WASTE FLOW PATTERN DETERMINATION	C	NE	S	H	24	430
EG-5	MULTISPECTRAL SIGNATURE – WASTE STORAGE SITES	C	NE	T	H	36	300
EG-6	LASER INTERFEROMETER RELAY SYSTEM	C	NE,D	S	H	12 – 60	235
EG-7	MULTISPECTRAL SIGNATURE OF GEOTHERMAL SOURCES	C	NE	S	H	12	165
EG-8	FOURIER TRANSFORM ANALYSIS OF LANDFORMS	I	NE	T	H	12	200
EG-9	THERMAL SENSING OF SEAMOUNTS	I	NE	T	H	12	300

TABLE 6-24 (page 6 of 7)

SUPPORTING TECHNOLOGY DEVELOPMENT DATA SUMMARY

STD NO.	STD TITLE	CRITICALITY	ACTIVITIES	OBJECTIVES	CONFIDENCE	TIME ESTIMATES (MONTHS)	COST ESTIMATE (THOUSAND DOLLARS)
	EARTH OBSERVATIONS – HYDROLOGY						
EH-1	WATER POLLUTION IDENTIFICATION TECHNIQUES	C	NE	S	M	24	400
EH-2	SNOW/ICE DEPTH MEASUREMENT TECHNIQUES	I	NE	S	M	12	200
EH-3	MODEL OF SNOW/ICE DEPTH SIGNATURE	I	S	T	M	6	100
EH-4	SOIL MOISTURE MEASUREMENT TECHNIQUES	C	NE	S	M	12	200
	EARTH OBSERVATIONS – METEOROLOGY						
EM-1	ATMOSPHERIC BOUNDARY LAYER MODEL	C	S	T	M	24	200
EM-2	ATMOSPHERIC EFFECTS BY SURFACE ALTERATIONS	I	S,NE	T	M	24	400
EM-3	SFERICS DATA INTERPRETATION	I	NE	T	M	36	400
EM-4	STELLAR SCINTILLATION EFFECTS	I	SE	S	M	24	300
EM-5	ATMOSPHERIC DENSITY APPLICATIONS	I	S	T	H	12	50
EM-6	ATMOSPHERIC DENSITY BY DUAL S/C	I	SE	S	M	36	500
EM-7	ZERO-G CLOUD PHYSICS LABORATORY	C	S,D	S	H	36	550 – 950
EM-8	AEROSOL DROPLET HANDLING	I	SE	T,O	H	6	30
EM-9	CLOUD PHYSICS EXPERIMENT PRIORITY	I	S	O	H	12	10
EM-10	CLOUD PHYSICS LAB-RELATED USES	I	S	T	H	12	300
EM-11	COHERENT RADIATION – POLLUTION DETECTION	I	NE	S	M	12	200
EM-12	ATMOSPHERE POLLUTION SIGNATURE ANALYSIS	C	NE	T	M	48	800
EM-13	ATMOSPHERE MODEL OF POLLUTION EFFECTS	C	S	T	H	24	60
EM-14	TROPICAL CLOUD SYSTEMS MODEL	C	NE	T	H	18	3000
	EARTH OBSERVATIONS – OCEANOGRAPHY						
EO-1	OCEAN POLLUTION IDENTIFICATION TECHNIQUES	C	NE	S	M	24	400
EO-2	OCEAN POLLUTION MODEL	C	S	T	M	24	100
EO-3	HEAT FLOW MEASUREMENT TECHNIQUES	C	NE	S	M	12	200
EO-4	SEA SURFACE HEATING MODEL	I	S	T	H	12	50
EO-5	CHLOROPHYLL CONCENTRATION MODEL	I	S	T	M	12	50
EO-6	OCEAN POPULATION MEASUREMENT TECHNIQUES	C	NE	S	M	12	200
EO-7	FISH-CHLOROPHYLL CORRELATION MODEL	I	S	T	M	12	100
EO-8	RADAR DETERMINATION SEA HEIGHT	I	S	T	M	24	100
EO-9	OCEAN CURRENT/HEIGHT MODEL	C	S	T	M	12	200
EO-10	ICE DISTRIBUTION MODEL	I	S	T	M	24	200
EO-11	OCEAN SALINITY MEASUREMENT TECHNIQUES	I	NE	S	M	12	150
EO-12	OCEAN PHYSICAL PROPERTIES MODEL	C	S,NE	T	M	24	150
EO-13	OCEAN DEPTH MODEL	C	S,NE	T	L	24	200
EO-14	BOUNDARY PROCESSES MEASUREMENT TECHNIQUES	I	NE	S	M	24	200
EO-15	SEA SURFACE ROUGHNESS MEASUREMENT TECHNIQUES	C	NE	S	H	24	1000
EO-16	SEA SURFACE ROUGHNESS MODEL	I	S	T	M	24	100
EO-17	ACTIVE/PASSIVE MICROWAVE RADIOMETRY	I	NE	S	H	24	500

TABLE 6-24 (page 7 of 7)

SUPPORTING TECHNOLOGY DEVELOPMENT DATA SUMMARY

STD NO.	STD TITLE	CRITICALITY	ACTIVITIES	OBJECTIVES	CONFIDENCE	TIME ESTIMATES (MONTHS)	COST ESTIMATE (THOUSAND DOLLARS)
	EARTH OBSERVATIONS – INSTRUMENTATION						
EI-1	TWIN METRIC CAMERA	C	D	S	H	24	2500
EI-2	MULTISPECTRAL CAMERA	C	D	S	H	24	1500
EI-3	TEN-BAND MULTISPECTRAL SCANNER	C	D	S	H	36	5000 – 10000
EI-4	SIDE-LOOKING RADAR IMAGER	C	D	S	H	48	10000
EI-5	UV-VISIBLE ABSORPTION SPECTROMETER	C	NE,D	S	M	24	900
EI-6	MULTI-CHANNEL OCEAN COLOR SENSOR	C	D	S	H	18	1000
EI-7	RADAR ALTIMETER/SCATTEROMETER	C	D	S	H	24	2000
EI-8	MICROWAVE SCANNER RADIOMETER	C	D	S	M	60	5000
EI-9	UHF SFERICS DETECTOR	C	D	S	H	24	700
EI-10	DATA COLLECTION SYSTEM	C	D	S	H	36	1000 – 10000
EI-11	STAR TRACKING TELESCOPE	C	D	S	H	31	3000
EI-12	ZERO-G CLOUD PHYSICS CHAMBER	C	D	S	H	48	400
EI-13	PHOTO-IMAGING CAMERA	C	D	S	H	36	20000
EI-14	INFRARED INTERFEROMETER SPECTROMETER	C	D	S	M	24 – 36	1000 – 2000
EI-15	MULTISPECTRAL TRACKING TELESCOPE	C	D	S	M	48	8000
EI-16	INFRARED SELECTIVE CHOPPER RADIOMETER	C	D	S	H	30	1000
EI-17	INFRARED FILTER WEDGE SPECTROMETER	C	D	S	H	24	1000
EI-18	INFRARED TEMPERATURE SOUNDER	C	D	S	M	24	1000 – 2000
EI-19	SATELLITE INFRARED SPECTROMETER	C	D	S	M	12 – 24	1000 – 2000
EI-20	TEMPERATURE PROFILE RADIOMETER	C	D	S	M	40	2000 – 3000
EI-21	VISIBLE WAVELENGTH POLARIMETER	C	D	S	M	36	1000 – 2000
EI-22	ULTRAVIOLET IMAGER/SPECTROMETER	C	D	S	M	48	2500
EI-23	LASER ALTIMETER	C	SE,NE,D	S	H	48	1645
	EARTH OBSERVATIONS – SYSTEMS						
ES-1	GROUND DATA PROCESSING CENTER	C	D	S	H	36	20000 – 40000
ES-2	AUTOMATIC DATA TRANSMISSION SYSTEM	I	S,D	S	H	48	6100
ES-3	SPACE RADIATION EFFECTS ON FILMS	I	SE,NE	C	H	4	300
ES-4	TEMPERATURE-HUMIDITY EFFECTS ON FILMS	I	NE	C	H	9	500 – 1000
ES-5	PHOTOGRAPHIC FILM STORAGE VAULT	C	D	S	H	12	1000 – 1500
ES-6	EVA-INSTRUMENT MAINTENANCE	I	S,SE,NE	O	H	7	275
ES-7	EVA-ANTENNA DEPLOYMENT	I	S,SE,NE	O	H	7	225
ES-8	EARTH OBSERVATIONS CREW OPERATIONS	I	S,SE,NE	O	H	10	300
ES-9	PHOTO-PROCESSING SYSTEM	C	S,D	S	H	18 – 36	1100 – 3200
ES-10	PHOTO-INTERPRETATION SYSTEM	C	S,D	S	H	22	1050 – 1100
ES-11	SPACECRAFT EFFLUENT EFFECTS	I	S,SE,NE	T,S	H	27 – 42	400 – 900
ES-12	REMOTE DATA DEGRADATION EFFECTS	I	NE	S	H	12	200

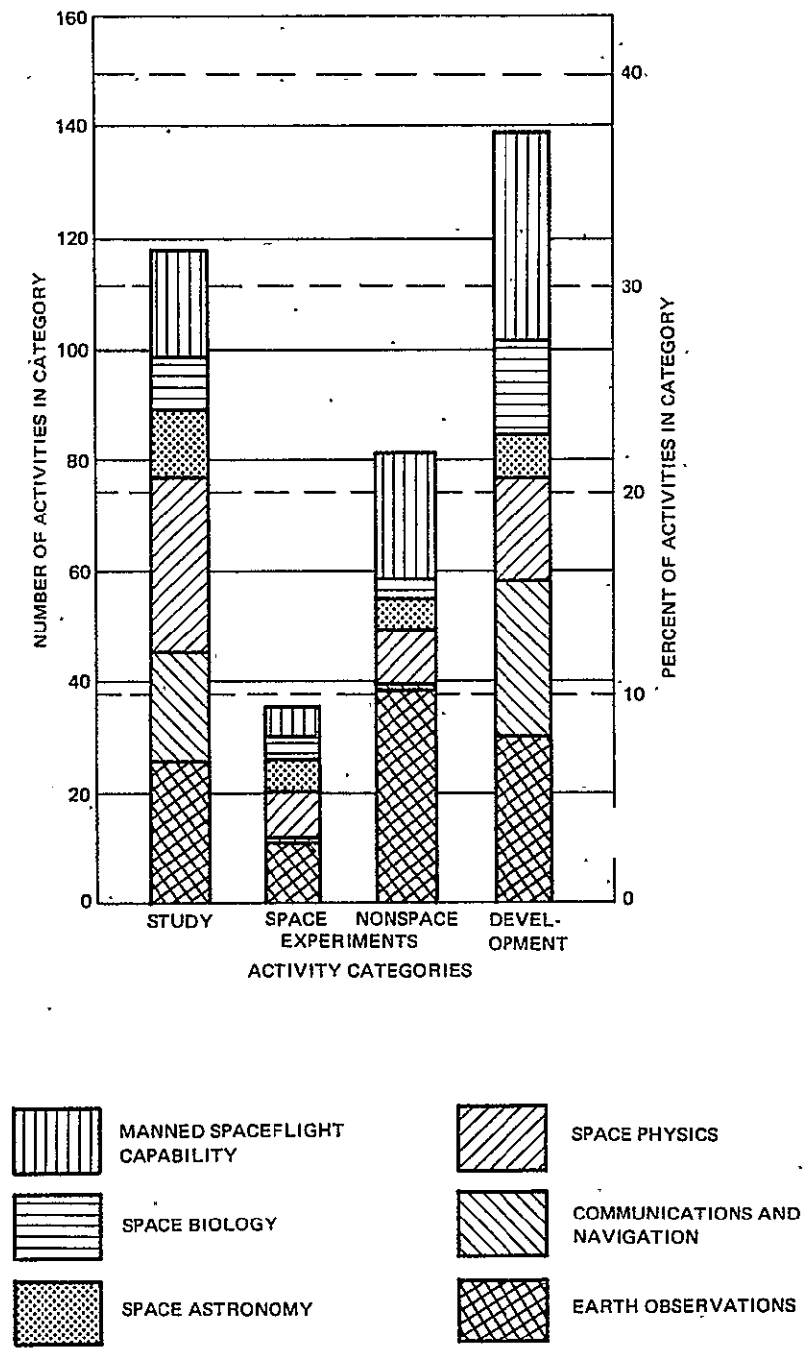

Figure 6-26. STD Activities Summary for All STD Items - 238 STD Items, 376 Activities.

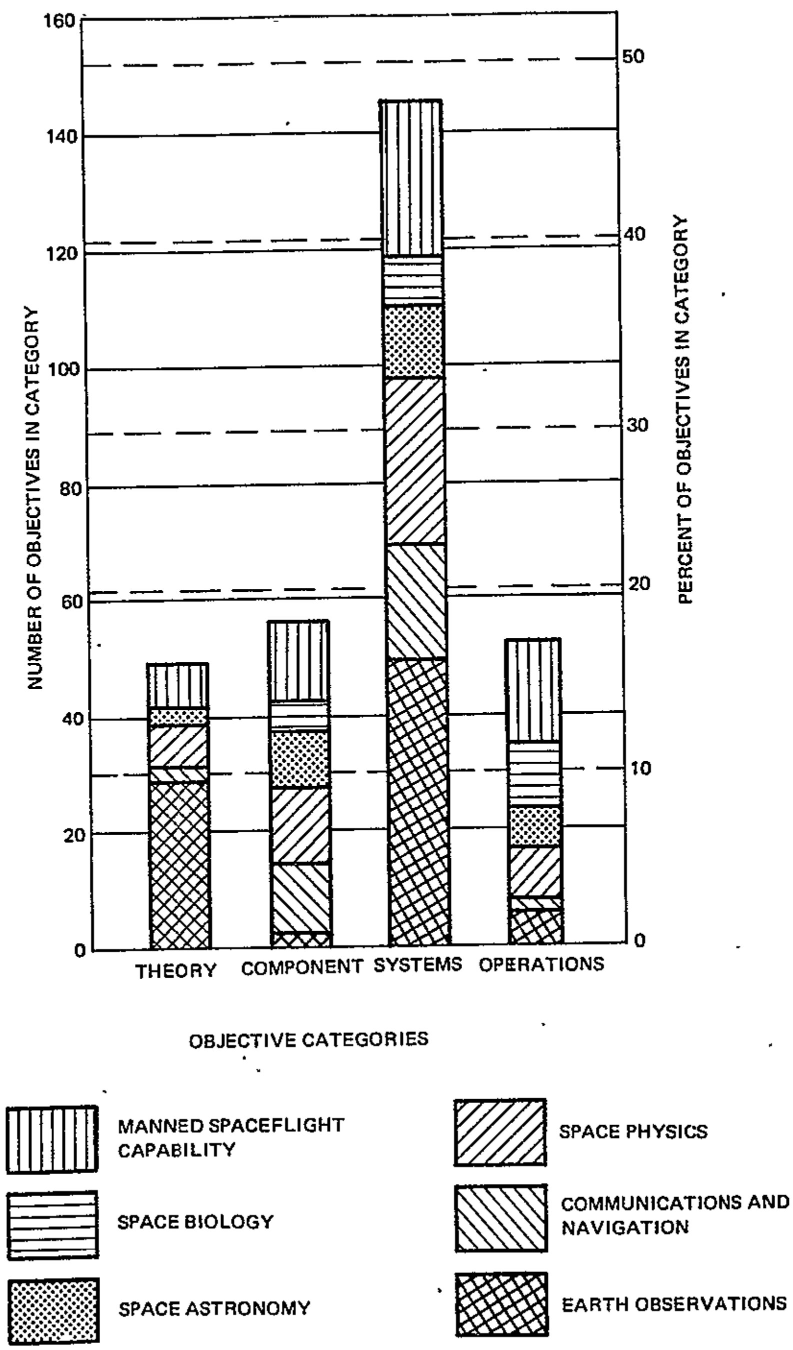

Figure 6-27. STD Objectives Summary for All STD Items - 238 STD Items, 305 Objectives.

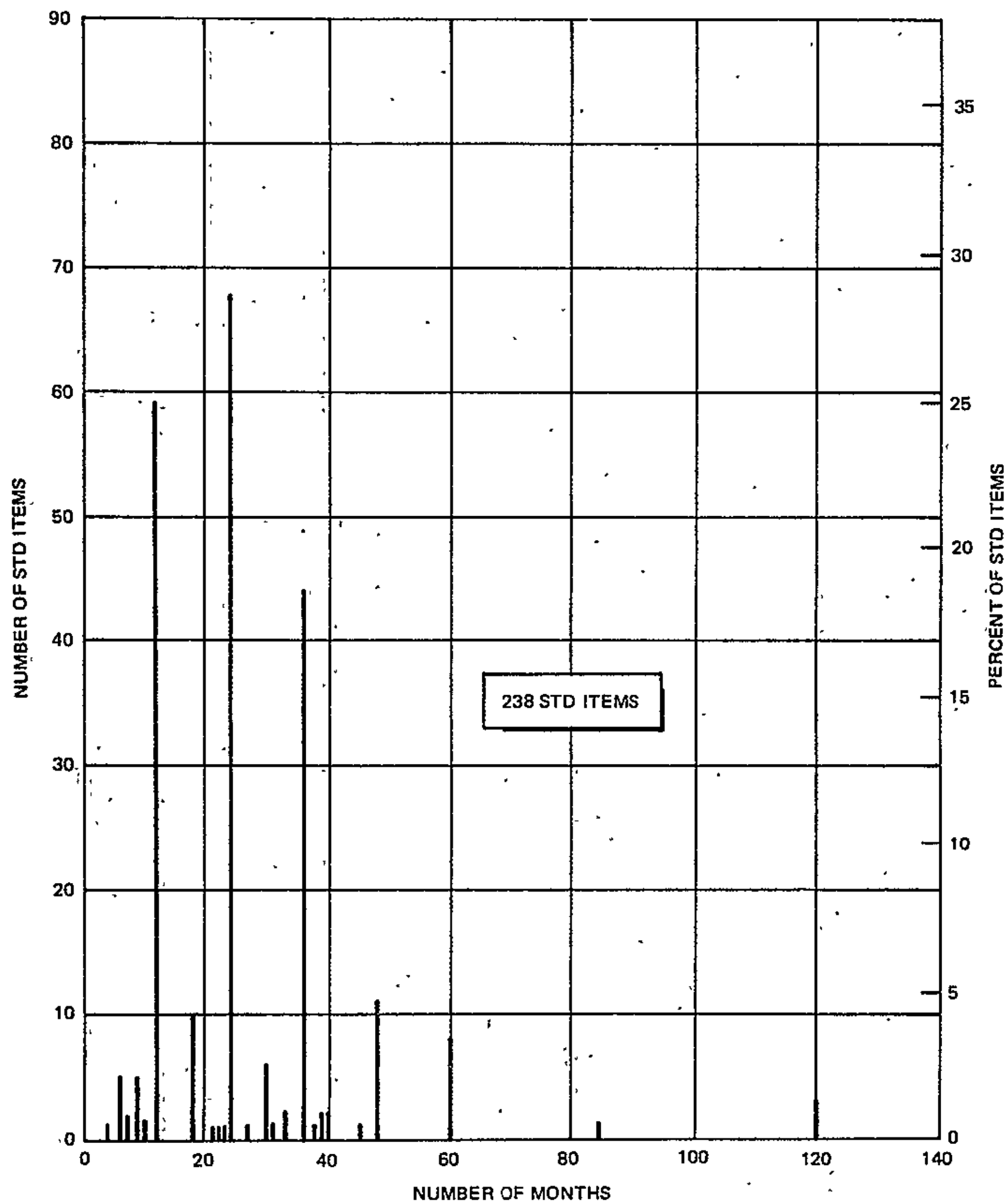

Figure 6-28. Time Estimate Summary for All STD Items.

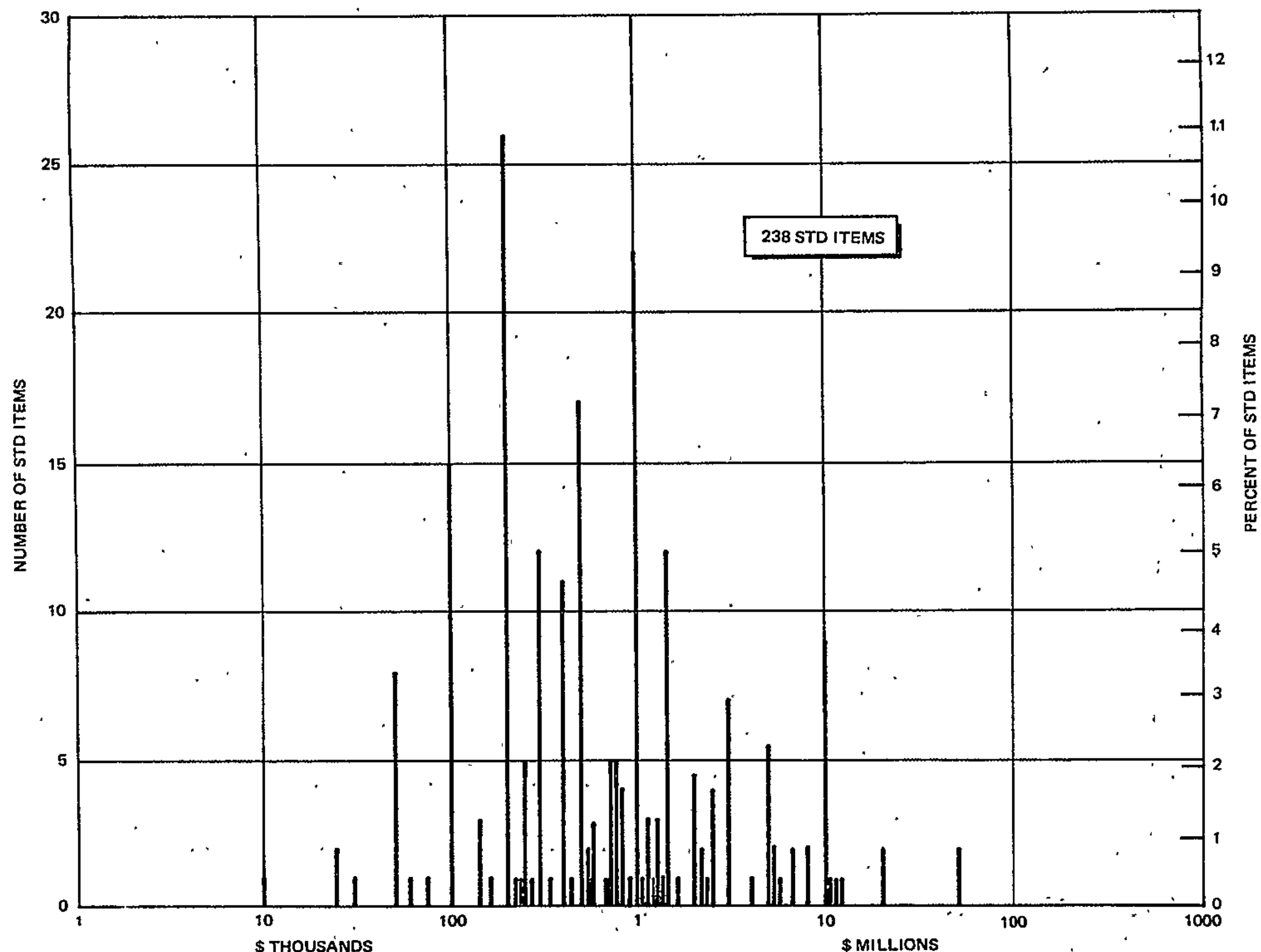

Figure 6-29. Minimum Cost Estimates - Summary for All STD Items

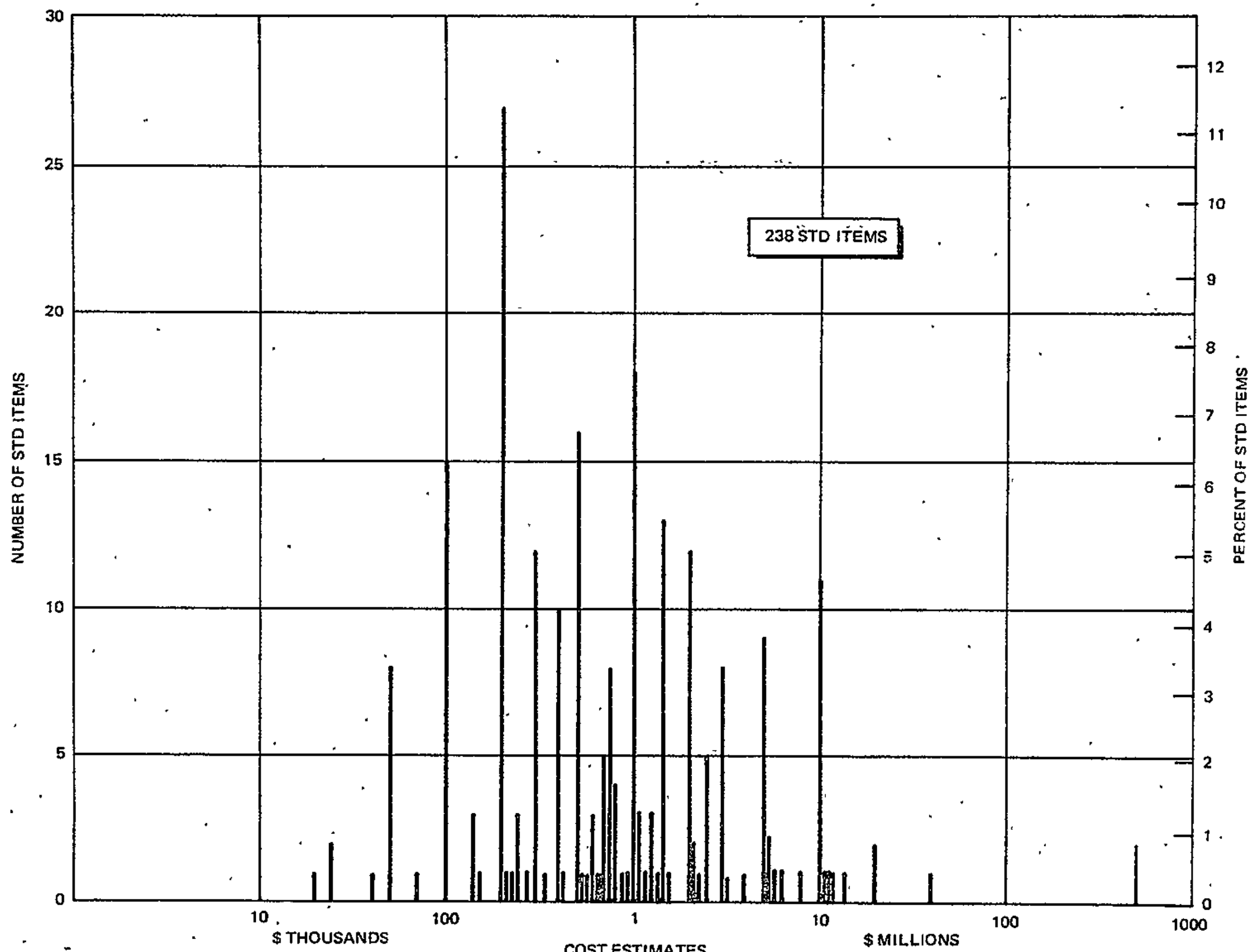

Figure 6-30. Maximum Cost Estimates - Summary for All STD Items

6.4.1. Experiment Commonality

Experiment commonality has two purposes. The first is to combine the several discipline-peculiar commonality matrices (Tables 6-4, 6-10, 6-13, 6-16, 6-19, and 6-22) into a unified matrix covering all the study disciplines. The second is to identify overlapping or identical STD requirements from different study areas. Attainment of these purposes permits group importance ranking and the formation of multidiscipline groups, defined in Subsection 6.4.2.

The second goal was sought first, the method being to assemble the STD analysis and compare STD requirements, item by item and discipline by discipline. For example, an STD item written originally for Earth Observations (item ES-6) was found to meet the requirements of Research Clusters 1-BR-1-1, 1-BR-1-3, 1-BR-3 and 1-BR-4. When overlaps or duplications were found, the degree and nature of commonality were described for later use in multi-discipline group derivation.

Display of the complete commonality matrix was not considered feasible, since such a matrix would contain 238 rows of STD items and 133 columns of research clusters (the total number of clusters and subclusters actually analyzed for STD requirements). Instead, a compacted version of the matrix was developed that shows only commonality outside the parent disciplines and omits the rows and columns in which no cases of commonality were observed. Figure 6-31 is an illustration of the structure of the commonality matrix. The areas labeled A through G represent the individual commonality matrices given in the list of tables above. The C's and I's (which stand for "critical" and "important") represent symbolically the out-of-discipline commonalities being discussed here. Table 6-25 is the actual matrix, in compacted form, showing the out-of-discipline commonalities identified for various STD items and research clusters. The data displayed here appear to be logical, since items like onboard film processing, crew operations, and cryogenic systems are expected a priori to relate to many clusters.

6.4.2. STD Grouping

The purpose of STD grouping was to form groups of STD activities that should be studied, developed, or otherwise considered together. In order to minimize

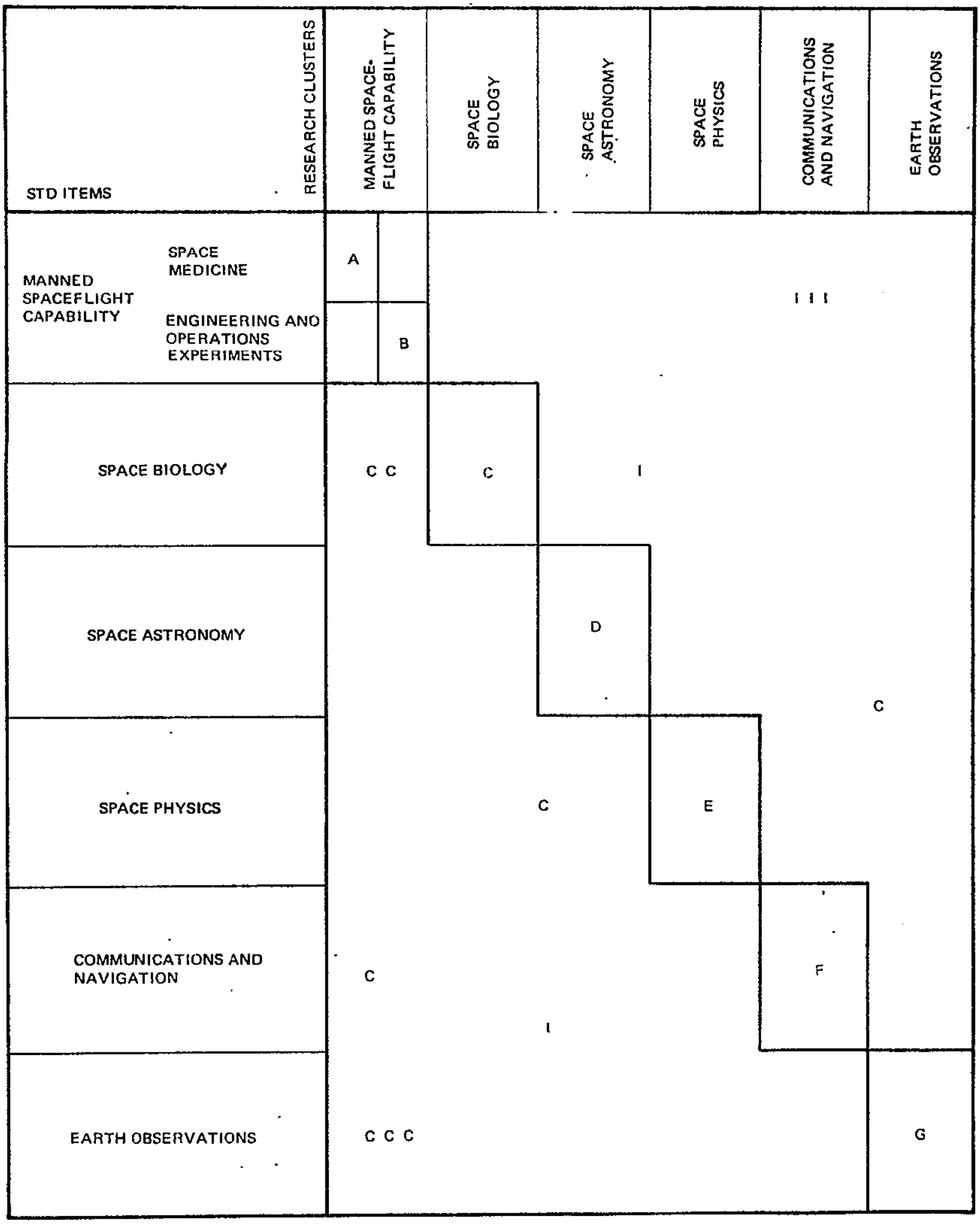

Figure 6-31. Illustration of the Structure of the Commonality Matrix.

TABLE 6-25

OUT-OF-DISCIPLINE COMMONALITY MATRIX

RESEARCH CLUSTER NUMBER

STD ITEMS	1-BM-4	1-BM-5	1-BM-6	1-BR 1 1	1-BR 1-3	1-BR 1-4	1-BR-2 1	1 BR 2 2	1 BR-3	1-BR-4	1-MM 1	1-MM 2	1-MM-3	1-MM-5		1-OE 1 1	1-OE-3	2 VB	2 IN	2-P/T	2-PL	3-OW	3-XR	3-LF	3-OB	3-DS
	1	2	3	4	5	6	7	8	9	10	11	12	13	14		16	17	18	19	20	21	22	23	24	25	26
MANNED SPACEFLIGHT CAPABILITY																										
BR 7 HAZARDOUS COMPLEX TASKS																I	I									
BR 8 TRAINING PROBLEMS AND EQUIPMENT						SEE TABLE 6-4										I	I									
MM 3 DARK ADAPTATION EQUIP AND TECHNIQUES																I	I									
EE 3 BIOWASTE RESISTOJET EVA				I	I	I			I	I						SEE TABLE 6-4										
OE 1 ASSEMBLY TECHNIQUES				I	I	I			I	I		I														
SPACE ASTRONOMY																										
A 6 ASSY ALIGN OF HI RESOLUTION TELESCOPE IN SPACE					I				I	I	I															
A 7 DEV FOR USE OF HI RESOLUTION TELESCOPE					I				I	I	I													SEE TABLE 6-13		
A 8 DEV USE OF PHOTO FILM – SPACE ASTRONOMY	I																									
SPACE PHYSICS																										
P 10 CONTAMINATION BY PHYSICS APPARATUS																						C	C		C	C
P 16 LASER HOLOGRAPHY																										
P 17 CONTAMINANT-PROOF EC&LS SYSTEM																		C	C	C						
P 25 FILM-VIDEO TAPE TRADE STUDY		I	I	I	I	I	I	I	I	I	I	I	I	I												
P 29 CRYOGENIC SYSTEMS																		C	C	C						
COMMUNICATIONS AND NAVIGATION																										
C 16 SOFTWARE DEVELOPMENT											I															
EARTH OBSERVATIONS																										
EM 1 ATMOSPHERIC BOUNDARY LAYER MODEL																										
EM-2 ATMOS EFFECTS BY SURFACE ALTERATION																										
EM 13 ATMOSPHERE MODEL OF POLLUTION EFFECTS																										
EM 14 TROPICAL CLOUD SYSTEMS MODEL																										
ES-3 SPACE RADIATION EFFECTS ON FILMS	I																	I	I	I	I					
ES-4 TEMPERATURE HUMIDITY EFFECTS ON FILMS	I																	I	I	I	I					
ES-5 PHOTOGRAPHIC FILM STORAGE VAULT	I																	I	I	I	I					
ES-6 EVA INSTRUMENT MAINTENANCE				I	I			I	I		I															
ES 7 EVA ANTENNA DEPLOYMENT				I							I															
ES-8 EARTH ORBITAL CREW OPERATIONS					I				I		I															
ES 9 PHOTO-PROCESSING SYSTEM	I																									
ES-10 PHOTO INTERPRETATION SYSTEM	I																					C	C		C	C
ES-11 SPACECRAFT EFFLUENT EFFECTS																						C	C	I	C	C

STD ITEMS	4-PC-1	4-PC-2	4-PC-3	4-PC-4	4-PC-5	4-PC-6	4-PC-7	4-PC-8	4-PC-9	4-PC-10	4-PC-11	5-N 1	5-N 2	5-P 1	5-P 2	5-P-3	5-P-4	5-TF 1	5-TF 2	5-CS-1	5-CS-2	5-NS 1	5-NS-2	5-NS-3	5-NS-4	5-NS-5
	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
MANNED SPACEFLIGHT CAPABILITY																										
BR 7 HAZARDOUS COMPLEX TASKS																										
BR 8 TRAINING PROBLEMS AND EQUIPMENT																										
MM 3 DARK ADAPTATION EQUIP AND TECHNIQUES																										
EE 3 BIOWASTE RESISTOJET EVA																										
OE 1 ASSEMBLY TECHNIQUES																										
SPACE ASTRONOMY																										
A 6 ASSY ALIGN OF HI RESOLUTION TELESCOPE IN SPACE																										
A 7 DEV FOR USE OF HI RESOLUTION TELESCOPE																										
A 8 DEV USE OF PHOTO FILM – SPACE ASTRONOMY																										
SPACE PHYSICS																										
P 10 CONTAMINATION BY PHYSICS APPARATUS																										
P 16 LASER HOLOGRAPHY																										
P 17 CONTAMINANT-PROOF EC&LS SYSTEM						SEE TABLE 6-16																				
P 25 FILM-VIDEO TAPE TRADE STUDY																										
P 29 CRYOGENIC SYSTEMS																										
COMMUNICATIONS AND NAVIGATION																										
C 16 SOFTWARE DEVELOPMENT																			SEE TABLE 6-19							
EARTH OBSERVATIONS																										
EM 1 ATMOSPHERIC BOUNDARY LAYER MODEL															I					I						
EM-2 ATMOS EFFECTS BY SURFACE ALTERATION															I					I						
EM 13 ATMOSPHERE MODEL OF POLLUTION EFFECTS															I					I						
EM 14 TROPICAL CLOUD SYSTEMS MODEL															I					I						
ES-3 SPACE RADIATION EFFECTS ON FILMS																										
ES-4 TEMPERATURE HUMIDITY EFFECTS ON FILMS																										
ES-5 PHOTOGRAPHIC FILM STORAGE VAULT	I	I	I	I	I	I	I	I	I	I	I															
ES-6 EVA INSTRUMENT MAINTENANCE																										
ES 7 EVA ANTENNA DEPLOYMENT												I	I	I	I	I	I	I	I	I	I	I	I	I	I	I
ES-8 EARTH ORBITAL CREW OPERATIONS																										
ES 9 PHOTO-PROCESSING SYSTEM																										
ES-10 PHOTO INTERPRETATION SYSTEM																										
ES-11 SPACECRAFT EFFLUENT EFFECTS																				I						

STD ITEMS	6-AF 1	6-AF 2	6-AF-3	6-AF-4	6-AF-5	6-G-1	6-G 2	6-G-3	6-G-4	6-G 5	6-G-6	6-H 1	6-H 2	6-H-3	6-H-4	6-H-5	6-H-6	6-H 7	6-M 1	6-M-4	6-M-5	6-M-6	6-O 1	6-O-2	6-O-3	6-O-6
	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78
MANNED SPACEFLIGHT CAPABILITY																										
BR 7 HAZARDOUS COMPLEX TASKS																										
BR 8 TRAINING PROBLEMS AND EQUIPMENT																										
MM 3 DARK ADAPTATION EQUIP AND TECHNIQUES																										
EE 3 BIOWASTE RESISTOJET EVA																										
OE 1 ASSEMBLY TECHNIQUES																										
SPACE ASTRONOMY																										
A 6 ASSY ALIGN OF HI RESOLUTION TELESCOPE IN SPACE																										
A 7 DEV FOR USE OF HI RESOLUTION TELESCOPE																										
A 8 DEV USE OF PHOTO FILM – SPACE ASTRONOMY																										
SPACE PHYSICS																										
P 10 CONTAMINATION BY PHYSICS APPARATUS																										
P 16 LASER HOLOGRAPHY																				I						
P 17 CONTAMINANT-PROOF EC&LS SYSTEM																										
P 25 FILM-VIDEO TAPE TRADE STUDY								I					I		I					I	I		I			
P 29 CRYOGENIC SYSTEMS	I	I	I	I	I	I	I	I	I	I	I	I		I	I	I	I	I	I			I	I	I	I	I
COMMUNICATIONS AND NAVIGATION																										
C 16 SOFTWARE DEVELOPMENT																				I						
EARTH OBSERVATIONS																										
EM 1 ATMOSPHERIC BOUNDARY LAYER MODEL																										
EM-2 ATMOS EFFECTS BY SURFACE ALTERATION																										
EM 13 ATMOSPHERE MODEL OF POLLUTION EFFECTS																										
EM 14 TROPICAL CLOUD SYSTEMS MODEL																										
ES-3 SPACE RADIATION EFFECTS ON FILMS																										
ES-4 TEMPERATURE HUMIDITY EFFECTS ON FILMS													SEE TABLE 6-22													
ES-5 PHOTOGRAPHIC FILM STORAGE VAULT																										
ES-6 EVA INSTRUMENT MAINTENANCE																										
ES 7 EVA ANTENNA DEPLOYMENT																										
ES-8 EARTH ORBITAL CREW OPERATIONS																										
ES 9 PHOTO-PROCESSING SYSTEM																										
ES-10 PHOTO INTERPRETATION SYSTEM																										
ES-11 SPACECRAFT EFFLUENT EFFECTS																										

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the effects of the subjective judgement that is inherent and unavoidable in this type of task, some general guidelines were given the study team:

- The basic objective of forming any STD group was to make a logical, cohesive work package.
- Items were considered to belong in the same group if the results derived from one item would influence the others.
- Items that appeared appropriate for a single contracted effort were grouped.

When the observed interactions were identified with the above procedure, the remaining upgrouped STD items were further tested one by one with the following questions: "If the characteristics of this STD activity were changed, would any other STD groups or activities be affected?" (The term "characteristics" referred to the overall scope of the STD activity - parameters, constraints, specifications, etc.) When the answer was "yes", either the item being tested was put in an existing group, or a new group was formed. If the answer was "no," the STD item in question became a single-item STD group. In this way, all items were ultimately grouped.

The procedure described above was carried out over all six study disciplines, with the results presented in Table 6-26 through Table 6-36. Each table lists the groups by name for the types of STD activities considered (studies, development, and experiments) and also shows the constituent STD items in each group. The asterisks denote items that also appear in the multidiscipline STD groups, which will now be described.

As mentioned in Subsection 6.4.1., the degree of overlap of STD items from different study areas was a subject of investigation. As this investigation progressed, it became apparent that STD groups composed of overlapping items from different disciplines could be formed in addition to those already listed above. Using the same ground rules as for single-discipline groups, multidiscipline groups were formed for studies and space experiments. The five groups that were formed (for both studies and space experiments) related to the following broad technological areas:

- Man's participation in Earth-orbital operations
- Optical instrument design
- Spacecraft effluent effects
- Cryogenic systems in space
- Photographic systems technology

It is clear from the group titles that the multidiscipline STD groups have major impacts on Earth-orbital experiments, independent of study discipline. For certain STD items, it was felt that this cross-discipline impact was so important that these items could be completely removed from their parent disciplines to appear only within the appropriate multidiscipline group. These items are identified with an asterisk in Tables 6-26 through 6-36, but to prevent confusion, they were left with their parent disciplines.

Table 6-37 lists the multidiscipline groups and the constituent STD items for both studies and space experiments. These groups include, but are not limited to the STD items identified with asterisks in Tables 6-26 through 6-36.

Table 6-26

BIOMEDICINE STD GROUPS

STD Group Title		STD Items
Studies		
	Inflight Body Fluid Analysis	BM-1
	Non-invasive Central Venous Pressure Measurement	BM-2
	Radiation Source	BM-5
	Animal Sensors	BM-9
Experiments in Space		
	None	
Experiments Not in Space		
	Space Thermal Enclosure	BM-6
	Sensitive Quantitative Evaluation of Reflex Functions	BM-7
	Endoradiosonde	BM-8
Development		
	Facilities and Chambers for Animal Experiments	BM-3, -4, -10
	Animal Sensors	BM-9
	Body Volumeter	BM-11
	Measurement of Transpulmonary Pressure	BM-12

Table 6-27

BEHAVIORAL RESEARCH STD GROUPS

STD Group Title		STD Items
Studies		
	Verbal Behavior Assessment Program	BR-5, -6
	Hazardous, Complex Tasks	BR-7*
	Training Problems and Equipment	BR-8*
Experiments in Space		
	None	
Experiments Not in Space		
	Simulated Zero-Gravity Experiments on Hearing and Psychomotor Degradation	BR-1, -3
	Verbal Behavior Assessment Program	BR-5, -6
	Hazardous, Complex Tasks	BR-7
	Training Problems and Equipment	BR-8
Development		
	Audio Tone Source Apparatus	BR-2
	Cognitive Measurements Test Module	BR-4
	Verbal Behavior Assessment Program	BR-5, -6
	Training Problems and Equipment	BR-8

*Candidate for multidiscipline group

Table 6-28

MAN-MACHINE INTEGRATION STD GROUPS

	STD Group Title	STD Items
Studies	None	
Experiments in Space		
	Dark Adaption Equipment and Techniques	MM-3*
Experiments Not in Space		
	Dark Adaption Equipment and Techniques	MM-3
	Habitability Experiment Support Package	MM-6
	Emergency Reaction Time from Sleep	MM-7
	Performance Aids	MM-9
Development		
	Display/Control Computer Capability	MM-1
	Display/Control Experimental Apparatus	MM-2
	Portable Metabolic Analyzer	MM-4
	On-Body Accelerometer	MM-5
	Habitability Experiment Support Package	MM-6
	Equipment for Sleep Experiments	MM-8
	Performance Aids	MM-9

*Candidate for multidiscipline group

Table 6-29

LIFE SUPPORT AND PROTECTIVE SYSTEM STD GROUPS

STD Group Title		STD Items
Studies		
	Multipurpose Fluid Physics Apparatus	LS-1
	Potability Measurement Microbial Detection	LS-6, -15
	Identification of Contaminants in Electrolysis Products	LS-9
	Waste Management System Concepts	LS-17
Experiments in Space		
	Fluid/Vapor Experiments	LS-2, -5
Experiments Not in Space		
	Fluid/Vapor Experiments	LS-2, -4, -5, -8, -9, -13
	Microbial Detection and Suppression	LS-15
Development		
	Fluid Flow Equipment Development	LS-1, -2, -4, -5, -7, -8, -13
	Hydrogenomonas Eutropha Systems	LS-10, -11
	Waste Management Systems Development	LS-14
	CO_2 Removal Methods	LS-12, -16
	Contaminant Monitoring and Removal	LS-3, -6, -9, -15

Table 6-30

ENGINEERING EXPERIMENT STD GROUPS

STD Group Title	STD Items
Studies	
Biowaste Electrical Propulsion and Resistojet Study	EE-1, -2, -3*
Space Communication and Navigation Laser Study	EE-4, -6*
Landmark Tracker System	EE-5
Experiments Not in Space	
Biowaste Electrical Propulsion Resistojet Experiments	EE-1, -2
Biowaste Resistojet EVA	EE-3
Development	
Biowaste Electrical Propulsion and Resistojet System Development	EE-1, -2
Laser Ranging System	EE-4
Landmark Tracker System	EE-5
Long-Range Optical Communications	EE-6

*Candidate for multidiscipline group

Table 6-31

OPERATIONS EXPERIMENT STD GROUPS

STD Group Title	STD Items
Studies	
Assembly Technique Study	OE-1*
Experiments Not in Space	
Assembly Technique Study	OE-1

*Candidate for multidiscipline group

TABLE 6-32 (page 1 of 2)

SPACE BIOLOGY STD GROUPS

STD Group Title		STD Items
Studies		
	Amino Acid Analyzer Study	B-1
	Zero-G Surgical Procedures	B-5
	Psychological Test Equipment	B-9, -10, -11
	Bunsen Burner Substitute	B-12
	Liquid Handling Techniques	B-13
	Blood Cell Counter	B-20
	Laboratory Integration and Equipment Analysis	B-21
Experiments in Space		
	Amino Acid Analyzer	B-1
	Zero-G Surgical Procedures	B-5
	Liquid Handling Techniques	B-13
	Small Particle Mass Measurement	B-20
Experiments Not in Space		
	Liquid Handling Techniques	B-13
	Small Particle Mass Measurement	B-20
Development		
	Amino Acid Analyzer	B-1
	Tissue Freezer (-180°C)	B-2
	Animal Biocentrifuge and Holding Units	B-3, -4
	Zero-G Autoclave	B-6
	Zero-G Incubator	B-7
	Tissue Processor and Stainer	B-8
	Psychological Test Equipment	B-9, -11
	Automatic Microbial Identification	B-14
	Zero-G Homogenizer	B-15

TABLE 6-32 (page 2 of 2)

SPACE BIOLOGY STD GROUPS

STD Group Title	STD Items
Zero-G Dialysis Equipment	B-16
Blood Cell Counter	B-17
Fluid Electrolyte Analysis	B-18
Advanced Plethysmograph	B-19
Small Particle Mass Measurement	B-20

Table 6-33

SPACE ASTRONOMY STD GROUPS

STD Group Title		STD Items
Studies		
	Operation and Use of High-Resolution Space Telescope Systems	A-1*, -2, -3, -8* -9, -10*, -11, -13*
	Logistics and Control of Telescope in Space	A-4*, -5*, -6*
	Development of Use of Photographic Film for Space Astronomy	A-7*
	Cooling of Solar Astronomy Telescopes	A-12
Experiments in Space		
	Assembly and Deployment of Space Telescope	A-1*, -5*, -8*
	Development of Use of Photographic Film for Space Astronomy	A-7*
	Acquisition and Tracking of Solar Targets	A-13*
Experiments Not in Space		
	Assembly and Deployment of Space Telescopes	A-1*, -5*, -8*
	Control and Maintenance of Telescopes in Space	A-3, -6*
	Target Acquisition and Tracking	A-10*, -13*
	High-Precision Stellar Photometry	A-11
	Cooling of Solar Astronomy Telescopes	A-12
Development		
	High-Resolution Optical Astronomy	A-1*, -8*
	Electronic Image Intensifiers	A-2, -9
	Telescope Operation in Space	A-7*
	Acquisition of Celestrial Targets	A-10*, -11, -13*
	Cooling of Solar Astronomy Telescopes	A-12

*Candidate for multidiscipline group

Table 6-34 (Page 1 of 2)

SPACE PHYSICS STD GROUPS

STD Group Title	STD Items
Studies	
Physics Experiment Design and Integration	P-1, -2, -4, -7, -8, -12, -14, -1 -19, -20, -24, -25*
Cosmic Ray Experiment	P-15, -27
Low-G Measurement and Isolation	P-5*, -6*, -11, -22
Cryogenic Equipment	P-36, -37, -38
Plasma Physics Research	P-31, -32, -34, -35
Contaminant Proof EC/LS System Study	P-17
Superconducting Material Study	P-28
Cryogenic Logistic Study	P-29*
Plasma Physics Subsatellite Study	P-30
Superfluid Research	P-39
Effluent Studies	P-9*, -10*
Experiments in Space	
Low-G Measurement and Isolation Tests	P-5*, -6*
Experiments on Molten Film Drawing	P-13
Space Tests of Cryogenic Systems	P-29*
Space Plasma Experiments	P-34, -35
Production of Hard Vacuum	P-9*

*Candidates for multidiscipline group

Table 6-34 (Page 2 of 2)

STD Group Title	STD Items
Experiments Not in Space	
Low-G Isolation Tests	P-6*
Contamination-Proof EC/LS System	P-17
Transition Radiation Detector	P-27
Superconducting Magnets	P-28
Cryogenic System Capability Tests	P-29*, -38
Contamination by Physics Apparatus	P-10
DC Electric Field Measurements	P-31
Development	
Liquid-Vapor and Droplet Apparatus	P-4
Heat Transfer and Wicking Apparatus	P-18, -21, -22
Cryogenic Support Equipment	P-23, -36, -37
Cosmic Ray Experiment Study	P-15, -27
Physics Laboratory Instruments	P-3, -31
Crystal Growing Apparatus	P-7
Physics and Chemistry Laboratory Apparatus	P-11, -24
Onboard Film Processor	P-26
Contaminant-Proof EC/LS System	P-17
Plasma Physics Subsatellite	P-30, -33
Intense Electron Sources	P-34

*Candidates for multidiscipline group

Table 6-35 (Page 1 of 2)

COMMUNICATIONS AND NAVIGATION STD GROUPS

STD Group Title	STD Items
Studies	
Millimeter Wave Experiment	C-2, -4, -5
Optical Communication	C-6*, -30*
Noise Source Experiment Plan	C-23, -24
Low-Noise Receiver	C-22
High-Efficiency RF Transmitters	C-26
Software Development Study	C-28
Self-Steering Phased Array Antenna	C-29
Satellite Tracking	C-7, -11, -14
Satellite Tracking Software	C-10, -18, -21
Clock Signal Test Transmitter	C-19
Software for Autonomous Navigation	C-15
Experiments in Space	
Laser Telescope Alignment	C-6
Experiments Not in Space	
Self-Steering Phased Array Antenna	C-29

*Candidates for multidiscipline group

Table 6-35 (Page 2 of 2)

STD Group Title		STD Items
Development		
	Millimeter Wave Experiment Package	C-1, -3, -4, -5
	Optical Communication Equipment	C-6, -30
	Low-Noise Receiver	C-22
	Computer Software	C-23
	Digital Ionosounder	C-25
	Efficient High-Power Transmitter	C-26, -27
	Software Development	C-28
	Self-Steering Phased Array Antenna	C-29
	Improved Satellite Tracking	C-7, -14
	Navigation and Surveillance Subsatellites	C-8, -16
	Satellite Tracking Software Equipment	C-10, -18, -21
	Laser Radar	C-12
	Autonomous Navigation Sensors	C-13
	Navigation and Surveillance Transponders	C-9, -17, -20
	Software for Autonomous Navigation	C-15
	Clock Signal Test Transmitter	C-19

Table 6-36 (Page 1 of 3)
EARTH OBSERVATIONS STD GROUPS

STD Group Title	STD Items
Studies	
Model of Snow-Ice Depth Signatures	EH-3
Model of Low-Atmosphere Circulation	EM-1, -2, -13
Atmospheric Density Data Applications	EM-5
Zero-G Cloud Physics Facility	EM-7, -9, -10
Model of Ocean Dynamics	EO-2, -5, -8, -9, -12, -13, -16
Model of Sea Surface Heating	EO-4
Model of Fish-Chlorophyll Correlation	EO-7
Model of Ice Distribution	EO-10
Automatic Data Transmission System	ES-2
Man's Utility in Earth Observations	ES-6*, -7*, -8*
Orbital Photographic Laboratory Study	ES-9*, -10*
Spacecraft Effluent Effects	ES-11*
Experiment in Space	
Agricultural Species Signature	EF-1, -2, -3
Stellar Scintillation Effects	EM-4
Atmospheric Density by Dual Spacecraft	EM-6
Aerosol Droplet Handling	EM-8
Laser Altimeter System	EI-23
Space Radiation Effects on Films	ES-3*
Extravehicular Maintenance and Development	ES-6*, -7*
Earth Observations -- Crew Operations	ES-8*
Spacecraft Effluent Effects	ES-11*

*Candidates for multidiscipline group

Table 6-36 (Page 2 of 3)

STD Group Title	STD Items
Experiments Not in Space	
Soil and Rock Signature Identification	EF-2, EG-2, 3, EH-4
Crop and Vegetation Signature	EF-1, -3
Quantification of Volcanic Morphology	EG-1
Waste Flow and Storage Experiments	EG-4, 5
Laser Interferometer Relay System	EG-6
Multispectral Signature of Geothermal Sources	EG-7
Fourier Transform Analysis	EG-8
Thermal Sensing of Seamounts	EG-9
Water Pollution Identification Techniques	EH-1
Snow and Ice Depth Measurement Techniques	EH-2
Atmospheric Effects by Surface Alterations	EM-2
Sferics Data Interpretation	EM-3
Atmospheric Pollution Detection	EM-11, 12, EI-5
Tropical Cloud System Model	EM-14
Ocean Boundary Dynamics	EO-13, -14
Ocean Property Dynamics	EO-1, -3, -6, -11, -12, -15, -17
Laser Altimeter System	EI-23
Environmental Effects on Films	ES-3, -4
Crew Operations Development Tests	ES-6, -7, -8
Spacecraft Effluent Effects	ES-11
Remote Data Degradation Effects	ES-12

Table 6-36 (Page 3 of 3)

STD Group Title		STD Items
Development		
	Twin Metric Camera	EI-1
	Multispectral Camera	EI-2
	Laser Interferometer Relay System	EG-6
	Zero-G Cloud Physics Laboratory	EM-7, EI-12
	Ten-Band Multispectral Scanner	EI-3
	Side-Looking Radar Imager	EI-4
	UV-Visible Absorption Spectrometer	EI-5
	Multichannel Ocean Color Sensor	EI-6
	Radar Altimeter-Scatterometer	EI-7
	Microwave Scanner Radiometer	EI-8
	UHF Sferic Detector	EI-9
	Ground Station Data Collection System	EI-10
	Star-Tracking Telescope	EI-11
	Photoimaging Camera	EI-13
	IR Interferometer Spectrometer	EI-14
	Multispectral Tracking Telescope	EI-15
	IR Selective Chopper Radiometer	EI-16
	IR Filterwedge Spectrometer	EI-17
	IR Temperature Sounder	EI-18
	Satellite IR Spectrometer	EI-19
	Temperature Profile IR Radiometer	EI-20
	Visible Wavelength Polarimeter	EI-21
	UV Imager-Spectrometer	EI-22
	Laser Altimeter	EI-23
	Data Transmission and Processing System	ES-1, -2
	Photographic Film Storage Vault	ES-5
	Orbital Photographic Laboratory	ES-9, -10

Table 6-37

MULTIDISCIPLINE STD GROUPS

STD Group Title	STD Items
Studies	
Man's Participation in Earth-Orbital Operations	BR, -7, -8; EE-3; OE-1, A-4, 5, -6; ES-6, -7, -8
Optical Instrument Design Study	EE-6; A-1, -8, -10, -13; P-5, -6; C-6, C-30
Effluent Effects	A-1, -8; P-9, -10; ES-11
Design and Operation of Orbital Cryogenic Systems	A-1, -8; P-29
Photographic System Technology	A-7; P-25; ES-9, -10,
Experiments in Space	
Man's Participation in Earth-Orbital Operations	MM-3; A-5; P-5, -6; ES-6, -7, -8
Optical Instrument Design Study	A-1, -13; P-5, -6
Effluent Effects	A-1, 8; P-9; ES-11
Cryogenic Systems	A-1, 8; P-29
Photographic System Technology	A-7; ES-3
Experiments Not in Space	
Not analyzed	
Development	
Not analyzed	

6.5 CONCLUDING REMARKS

This section summarizes the more significant general conclusions from the technology analysis. These include the supporting technology requirements, by subdiscipline, from Subsection 6.2.; the activities, objectives, development times, and costs, from Subsection 6.3.; and the results of commonality and grouping studies from Subsection 6.4.

6.5.1. Supporting Technology Requirements

Manned Space Flight Capability

The specific technology development needs identified in this discipline are generally in the areas of biomedical instrumentation development, animal housing and instrumentation development, continued ground-based behavioral research, development of facilities for performing experiments in space, and development of advanced life support and engineering systems for flight evaluation. Of particular importance are the development of long-lead time integrated systems for flight evaluation, animal support facilities and test equipment development, and the active continuation of bioinstrumentation development and ground-based behavioral research.

Space Biology

In general, the supporting technology development items in this discipline require the extension of present terrestial biology laboratory test equipment, support equipment, and analyses techniques to the zero gravity environment. There is much commonality between these requirements and those of the biomedical subdiscipline, and the goals of the IMBLMS program. It is anticipated that many of the concepts and equipment items developed during these activities will be applicable to the needs of this discipline.

Space Astronomy

The supporting technology development items in this discipline are, in general, concerned with the definition, development, and verification of a number of advanced space telescope subsystems and operations techniques. Specifically, state-of-the-art advances are required in the areas of telescope optical systems, thermal control, target acquisition, and tracking subsystems, logistics, assembly, alignment and operations techniques, film protection and use, and improved electronic in age intensifiers. These advancements require studies, development, and experiments (both ground and in space).

Space Physics

Development requirements were identified for instrumentation and apparatus to perform the experiments (i.e., melting apparatus, superfludity test apparatus, D/C electric field measuring device, etc.), for operations techniques (i.e., material heating plasma physics subsatellites, etc.), and for supporting measurements and systems (i.e., hard vacuum requirements, D/C field measurements, contamination problems, cryogenic systems, etc.). Four items felt to be particularly significant are: definition of techniques to assure availability of a hard vacuum, measurement of D/C electric fields as low as 1mv/m, maintenance and management of large quantities of cryogenics, and external and internal contamination control.

Communications/Navigation

The majority of the STD items described in this discipline are for the development of the systems and components which will be evaluated as part of the flight experiment program. Examples of such systems which represent a first-order technological challenge are the 94 GHZ amplitude and phase measurement system which is presently limited to 18 GHZ for automated systems, development of a high-speed correlator, improved satellite position determination, which calls for an order of magnitude increase in capability, and development of landmark trackers.

Earth Observations

The STD heading of the top of the list is the ground data processing center. Due to the large amount of data to be transmitted, technology is required for bulk storage, easy retrival of data, and an emphasis on automatic data processing.

Effluent effects is another major impact area, across all subdisciplines, which will require an assessment prior to detailed spacecraft design and operation plans. In the photographic area, the technology envolved with the space radiation effects on films must be assessed and a lighter and more compact film storage vault, than presently proposed for Skylab, must be developed.

6.5.2. Summary of Activities, Objectives, Development Time, and Costs

The majority of the STD items identified were related to development of various components and systems. Time estimates to complete were predominantly in the two to three year range, and individual STD items are in general below $800K. Largest costs and longest lead times were generally for the development of integrated systems suitable for flight operation or evaluation, and for development of an upgraded ground data center.

6.5.3 Commonality and Grouping

Many of the research clusters had common STD requirements which could be collected into common groups. This was true for both within experiment discipline and across experiment discipline considerations. Five common groups which were defined from the multidiscipline analysis were:

- Manned earth orbital operations
- Optical instrument design
- Effluent effects
- Design and operation of cryogenic systems
- Photographic system technology